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INDIAN CENTRAL COTTON COMMITTEE.

THE PERIODIC PARTIAL FAILURES OF AMERICAN COTTONS; THEIR CAUSES AND REMEDIES

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PREFACE

The main findings of the investigations on the partial failures of the Punjab-American cottons in the Punjab have been embodied in this volume. For detailed results on each line of investigation the reader is referred to the scientific papers either already published or in course of Publication in the *Indian Journal of Agricultural Science.* The bibliography of relevant literature that has a bearing on the different aspects of the work is given in the text at the end.

I take this opportunity of expressing my deep sense of gratitude to Sir. H. R. Stewart, Esq., C.I.E., I.A.S., Vice-Chairman, Imperial Council of Agricultural Research the then Director of Agriculture, Punjab, for giving all help, facilities and support during the period of the investigation. *It can be truly said that this piece of work which has proved to be of scientific as well as of practical value would not have been possible had it not been for him.* I have also to express my thanks to the Presidents and the members of the Agricultural Research Sub-Committee of the Indian Central Cotton Committee for their constructive criticisms and suggestions during the progress of the work.

Thanks are also due to the authorities or owners of various commercial farms in the Punjab, especially the B. C. G. A. Farm, Khanewal, for providing all facilities for the conduct of field experiments.

I received most willing co-operation and help from all members of my staff, who spared no efforts to do the work entrusted to each of them. They did not spare themselves and worked on all days irrespective of holidays, Sundays or office hours. An idea of the quantity of work done by them can be obtained from the data published in the form of scientific publications in the *Indian Journal of Agricultural Science.*

The whole research was carried out at the Punjab Agricultural College, Lyallpur under a scheme of the Indian Central Cotton Committee.

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PREFACE TO THE SECOND EDITION.

The American cottons (*G. hirsutum*) ever since their introduction in different parts of India have been subject to two important physiological diseases *viz.* 'bad opening' of bolls or *tirak* and the red leaf disease. The investigations reported in this book deal with these two 'diseases' which were found to be prevalent in the two most important American cotton growing tracts in India *viz.* the Punjab and Sind.

In the Punjab the causes of periodic failures of American cottons had been subject of discussion ever since 1919 when the first major failure of the crop occurred. The crop exhibited symptoms of *tirak* or 'bad opening' of bolls with premature shedding of leaves. Since that year various theories or views were expressed regarding the causes that caused such failures of crop. As these failures caused great financial losses both to the cotton growers and to the Provincial Government a scheme was prepared in 1932 by the Punjab Government to conduct scientific investigations of the whole problem and the Indian Central Cotton Committee was approached to provide the necessary funds. The scheme was sanctioned by the Committee and it started working in March 1935.

Very many lines of pure physiological research on cotton were proposed in the Scheme but the permission of the then Director of Agriculture, Punjab, Sir Herbert Stewart, Kt., C.I.E., was obtained to tackle this problem of *tirak* and periodic failures of cotton as it appeared to the author under field conditions.

Observations made on the crop during the years 1935 and 1936 showed that the fields of cotton exhibiting all the symptoms of *tirak* or 'bad opening' of bolls described for the previous failure years were present even though these two years proved to be the normal years of very high yields. It was therefore proposed in 1937 to investigate the soil conditions associated with *tirak* symptoms in such fields. Owing to difference of opinion in the Committee arising out of an assertion made before, that soil factors did not play any part in the disease', Dr. T.G. Mason, F.R.S. was invited in 1937 in a consultative capacity to give his views. He agreed with the author's findings and conclusions and soil investigations were undertaken.

Two soil conditions associated with *tirak* were discovered in 1938 and the weather conditions that aggravated the intensity and the spread of *tirak* became known in the year 1939 which fortunately for the investigation proved to be a cotton failure year. The ameliorative effect of delaying sowing on *tirak* by two to four weeks on both soil types was first discovered in 1938 and the necessity of closer spacing than 3 feet between two cotton rows so far adopted in the Punjab was also found out in 1939. Extensive trials of this simple measure to remedy *tirak* were undertaken from 1940 to 1942 in the different districts. As a result of 41 complex experiments optimum sowing periods in combination with closer spacing were fixed for each variety and for each cotton tract.

The detailed results of the investigation conducted at the Punjab Agricultural College, Lyallpur, from 1935 to 1942 have already been published in 16 seperate parts in the Indian Journal of Agricultural Science, Volumes *9* to *15*.

The Sind-American Cottons in Sind since they entered into large scale cultivation after the completion of Lloyd barrage in 1932 have also been reported to suffer from the 'bad opening' of bolls although partial failures of crop as in the Punjab had not occurred. After the Punjab investigations were completed in 1942, investigations in Sind to determine the causes of 'bad opening' of bolls were undertaken and completed in 1946. The same causes and the remedy for the 'bad opening' of bolls discovered in the Punjab-American cottons were found to hold good for the Sind-American cottons in Sind. It was also explained why such partial failures of the cotton crop had not occurred in Sind. The main findings of the investigations conducted in Sind are now incorporated in this second edition of the monograph.

Side by side the investigations conducted on the 'bad opening' of bolls in Sind-American cottons, the factors that produced the red leaf disease and its frequent and wide-spread occurrence in south Sind have been determined. This 'disease' was found to be present to a greater or lesser extent every season in this tract. The two types of the red leaf, the yellow-red and the green-red have been differentiated and these two types of the red leaf have been found to be associated with two different types of soils. The yellow-red type was found to be the most prevalent type and remedial measures for lessening the intensity and spread of the yellow-red leaf have been recommended.

The original title of the monograph has been retained with the omission of the word 'in the Punjab' as the revised edition contains the investigations conducted in Sind.

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FOREWORD.

Of the many achievements of the Agricultural Departments in India, few, if any, have equalled and none has surpassed, in point of financial gain which it has conferred on the cultivator, the introduction of American staple cotton into the Canal Colonies of the Punjab. To him its replacement of short staple indigenous cotton annually brings crores of rupees of additional income, whilst trade and industry also have reaped their share of the benefits. In 1912, when its possibilites began to be recognised, Punjab-American cotton occupied an area of about 10,000 acres, out of a total Punjab crop of about 1,450,000 acres. In 1943-44 the 1,840,000 acres under these staple varieties represented 70 per cent of the total 2,602,000 acress of cotton grown in the province. Some idea of what this cotton means to the cultivator may be obtained from the fact that for each rupee per maund by which the price of its *kapas* (seed cotton) exceeds that of indigenous short staple cotton, the total added income to the Punjab cultivator in a single year at the present time is more than one crore of rupees and, though not customary, a premium of Rs. 10 per maund in some years is not unknown. Nor does this give an adequate picture of the benefits which the introduction of this cotton has conferred, for, since the advent of perennial irrigation in Sind, Punjab-American cotton and its Sind descendants constitute the principle cotton crop in that province also.

In 1919 the Punjab-American cotton crop received its first serious setback when it was attacked by an unknown "disease" which caused the leaves of the plants to turn first yellow and then a deep red colour and to shed prematurely; the bolls opened incompletely; the seed inside them was undeveloped and the fibre was trash. The yield per acre of this very poor quality seed coton was only about 25 per cent of the normal outturn from a healthy crop. These "failures" of the Punjab-American cotton crop were repeated partially or completely on seven subsequent occasions, in 1920, 1921, 1926, 1927, 1928, 1931, and 1932.

Various theories were advanced from time to time to explain this condition which became known as *tirak*. They included lack of sufficient irrigation, white fly attack, faulty nutrition of the plant, excessive plant growth in July and August, severe drought in September, high temperature and low humidity in September-October, heat stroke, dust-storms, water-logged soil due to heavy rain and non-dehiscence of anthers. None of these possibilities, however, offered a satisfactory solution of the mystery of the occasional "failures" of the cotton crop.

In 1935 the first serious attempt scientifically to investigate the cause of this peculiar and financially disastrous condition of the cotton plant was undertaken when the Indian Central Cotton Committee provided the necessary funds for the employment of special staff for the purpose and the Punjab Government the required facilities in land, laboratories, etc., at Lyallpur. The investigation was completed in 1943 and this Monograph describes the results. The story which it unfolds is a striking example of how investigations into the realm of pure science can be turned to practical account in everyday agricultural practice.

Until he undertook this investigation Prof. Dastur had no previous contact with or knowledge of the cotton plant. He began this research by observations on

its internal structure and he discovered an extraordinary and previously unrecorded state of affairs in that the structure of the chloroplasts had broken down, the whole internal economy of the plant had become disorganised and large accumulations of starch and of tannin were found.

Prof. Dastur then succeeded in reproducing these extraordinary internal condition in the cotton plant, together with the outward *tirak* symptoms of bad boll opening, undeveloped seed and trashy lint, by subjecting the plant during growth to concentrations of certain salts in the pure sand in which he grew it. At this stage of the investigation, through the co-operation of the Empire Cotton Growing Corporation, London, the services of Dr. T. G. Mason from Trinidad were obtained in a consultative capacity and it was agreed that all the evidence then available warranted a tentative conclusion that the origin of the trouble was to be found in the soil.

In his subsequent investigations, Prof. Dastur not only proved the correctness of this conclusion but found that tirak was produced in soils of two distinct types, namely, light sandy soils deficient in nitrogen and soils whose sub-soils possessed high alkaline content.

Having ascertained the cause of *tirak*, Prof. Dastur then set about discovering the remedy. For soils of the first type, this was found in the application of nitrogenous fertilisers at an appropriate stage in the growth of the cotton plant. The solution of the problem in soils of the second type was found ultimately to lie in delaying the date of sowing, but this treatment produced a plant much reduced in size and adversely affected the yield of cotton per acre. Prof. Dastur completed his achievements by overcoming this serious defect through increasing the seed rate per acre and progressively reducing the spacing between coton plants as the sowing date was delayed.

To the scientific world, Prof. Dastur has made a valuable contribution during the eight years covered by his research into this problem, whilst for the practical cotton grower he has not only determined the causes of the heavy financial losses which were suffered in certain years in the past but has provided practical remedies by which these losses can be avoided in the future. To the Indian Central Cotton Committee which made this research possible by its unstinted financial assistance, the Punjab cotton grower and the cotton manufacturing industry stand deeply indebted.

H. R. STEWART
Vice-Chairman,
Imperial Council of Agricultural Research.

25th September, 1944.

CONTENTS.

CHAPTER VII

PAGE.

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

PAGE.

CHAPTER I

INTRODUCTION

4F Punjab-American cotton (*G. hirsutum*) was first given out to the cultivators in 1914 by the Department of Agriculture, Punjab. The original stock, from which this selection was made by D. Milne, the then Economic Botanist, was very probably received from Dharwar. 289F Punjab-American cotton was also selected from the same source. Further selections were made by the Scientific Staff of the Department from these two strains. L.S.S. and 289F/43 were selected from 4F and 289F respectively and these new strains are now being widely cultivated. L.S.S. and 4F. are generally grown in Sarghoda, Sheikhupura, Jhang and Lyallpur districts while 289F and 289F/43 are grown in the western tracts of the Punjab. A further selection known as K25 was obtained from 289F by the staff of the B.C.G.A. Farm at Khanewal. 289F/K25 had gained great popularity in the south-western tracts, especially in Multan district, but it was now replaced by another selection named 289F/124.

The acreages under American cottons in the Punjab have fluctuated very widely from year to year. On account of high prices of cotton that prevailed after the last Great War the acreage under American cottons jumped up from 401,000 acres in 1921 to 1,134,000 acres in 1926 but it again dropped to 750,000 acres in 1927 on account of the failure of the crop in the year 1926. American cotton failures again occurred in 1927 and 1928 and, therefore, the area under Americans fluctuated between 7 and 8 lacs acres up till 1934 when the acreage under Americans again went up to 1,305,000 in 1935. The reasons for this increase in acreage were low prices for short-stapled cotton and very good yields of American cottons from the year 1933 onwards when the average yields per acre went up to 7.3 maunds as compared with the average of 5 maunds in the previous years. The area under American cottons have up till now fluctuated between 12 and 18 lacs acres.

A certain proportion of *desi* cotton is also grown in the irrigated tracts of the Punjab, where American cottons have been introduced. The acreage under *desi* cottons varies from district to district and year to year but is generally much less than that of Americans in each year and in each district. The average acreage of *desi* for the eight important American cotton growing districts in 1935-36 was 499,464 as compared with 1,234,297 for Americans. *Zamindars* would very probably have put their entire area under Americans if the same were not subject to the physiological trouble of defective boll-opening, popularly known as *tirak*. *Tirak* was present in a very severe form during the failure years referred to above, and was mainly responsible for lowering the yields of Americans by nearly 50% of the normal.

The climatic and the soil conditions in the central and the western tracts of the Punjab are favourable for the growth of American cottons wherever facilities for canal irrigation are available. The sandy loam soils with the climatic advantage of long and warm summer days are particularly favourable for vigorous vegetative growth of the plants. On soils of medium fertility the plants of 4F cotton attain a height of 3 to 4 ft. and produce numerous branches ; so much so that by the month of September the crop when sown at a row to row distance of 3 ft. becomes so thick that it is not possible to pass through without damaging it. The flowering phase sets in when the day length shortens and the temperatures fall in the month of September. The fruiting season begins in September and extends up to the third week of October.

Pickings begin in November. The fruiting period is of a short duration as compared with the length of the vegetative phase which begins in May and practically ends when the reproductive phase sets in.

A study of the cotton crop in the different phases of growth in the Punjab leads one to conclude that the vegetative and reproductive phases of the crop were physiologically unbalanced. The vegetative growth of the plant appeared to be in excess of what was produced by it in the form of bolls. The above impression was further confirmed by the fact that the sowings of American cottons have been gradually shifted as experience was gained. In the early years of their introduction in the Punjab the general sowing time was the month of March which was then gradually shifted to April. In later years the month of May has been the main sowing period.

As the periodic failures of American cottons caused great financial losses to the cotton growers and to the Government of the province as well, they had been a subject of investigation from 1919 onwards. Attempts were made to discover the causes responsible for such periodic occurrence. Various views were expressed regarding the causes of cotton failures and they are briefly discussed below.

(i) Previous views on the Causes of Cotton Failures.

Roberts (1929, 1930) from his observations made in the failure years of 1927 and 1928 on the crops sown in May and early in June at the British Cotton Growers' Association Farm at Khanewal surmised that the White Fly was the cause of *tirak* and of low yields in the failure years. He attributed the superiority of early June-sowings to May-sowings to the greater damage caused by White Fly to the latter than to the former.

This view was subsequently supported by Thomas (1932). Detailed investigations were therefore undertaken by the Department of Agriculture with the financial assistance of the Indian Central Cotton Committee to determine the rôle played by the White Fly in the development of *tirak* in American cottons. Afzal Husain and Trehan (1933) showed that though the White Fly was a serious pest of cotton causing flower and boll shedding in American cottons, it was not responsible for causing the widespread failures of cotton. It may be mentioned that the failures of cotton occurred even in years which were not the White Fly years.

Milne (1921, 1922, 1928) expressed different views regarding the cause that gave rise to these failures. Amongst them may be mentioned, in the order they were expressed, (1) inadequacy of water supply in the months of September and October which were dry and warm, and (2) the crop suffered from heat stroke in the early stages of growth on account of high temperature and low humidities in May-June. A number of suggestions regarding the possible causes of this periodic occurrence have been recorded by Milne (1928). None of these statements or suggestions was, however, supported with experimental or any other kind of evidence.

Trought (1931) attributed these failures to the operation of three kinds of factors, *viz.*, climatic, biotic and physiological. He had definitely ruled out the soil factor as playing any part in the development of *tirak* in these failure years. The part played by the soil conditions in the development of *tirak* in American cottons has already been reported in the contributions by Dastur (1941b and 1942) and Dastur and Samant (1942), on the *tirak* problem and will be discussed in subsequent Chapters. It was therefore unnecessary to discuss here the views expressed by Trought (1931).

(*ii*) Symptoms of *Tirak*

American cotton plants were reported to show, during the failure years, premature cracking of bolls with immature seeds and poor quality of lint. The important observation, symptomatic of the disease, was yellowing and reddening of leaves, which appeared towards the beginning of the reproductive phase, intensified with age and was followed by early defoliation. Though this was an important observation, its significance escaped attention at that time. Yellowing and reddening of leaves indicated internal starvation for want of some essential elements like nitrogen, magnesium or phosphorus. Such symptoms in leaves have been described by various workers in the case of other crops that suffer from a deficiency of any one of the rare or essential elements (*vide* Russell, 1937). The immaturity of seeds in *tirak* affected plants also pointed to a deficieny of potash. The cotton plants in some parts of America had been reported to produce immature seeds when they suffered from what was called 'potash hunger' (Skinner & Pate, 1925 ; Wood, 1935; Neal and Gilbert, 1935).

The symptoms of *tirak* described above were reported to appear when crop was in its reproductive phase during all the failure years and there was, therefore, an additional reason to conclude that there was some disturbance in the mineral uptake of the plants as the various elements were known to be required in the maximum amounts at the reproductive stage.

The crazy top disorder in Pima cottons in Arizona in the United States which was first noticed by Cook (1924) bears some resemblance to *tirak* symptoms in the Punjab. The bolls of plants suffering from this disorder were also small and deformed and were reduced in number. No mention had been made about the maturity of seeds or the quality of lint. Though no data of the physical and chemical properties of the soil are available the 'disease' was associated by King and Loomis (1927) with the impervious nature of the subsoil within two or three feet of the soil surface. It was also stated by them that in some cases no differences between soil characters of the 'diseased' and the normal areas were noticed. In the absence of more information regarding the properties of the soil in the affected area, and the morphological characters of the cotton plants that suffered from the crazy top disease, it was difficult to say whether it bore any resemblance to the physiological condition of *tirak* in the Punjab-American cottons.

CHAPTER II.

VARIATIONS IN THE YIELDS OF SEED COTTON.

As the partial failures of American cottons occurred in all the important districts of the Punjab, it was thought necessary to determine the depressions in the normal yields that occurred in these years in the whole province as well as in each of the important cotton growing districts.

Such a study would reveal what were the bad, partially bad and good crop years and to what extent the yields were depressed or enhanced in the bad or the good years of the cotton crop in the Punjab.

Acreages under American and *desi* cottons in eight important American cotton growing districts of the Punjab were obtained for the period 1921-1935

from the Season and Crop Reports published by the Punjab Government. Similarly the total number of bales of American and *desi* cottons pressed in each district and for the whole province were obtained from the same source. As no separate figures for the acreage or bales for American and *desi* cottons were available prior to 1921 the failure years of 1919 and 1920 could not be included in this study. In order to convert the figures for lint (1 bale=400 lbs. of lint) into those of seed cotton, ginning percentages for American and *desi* cottons were taken as 30% and 35% respectively. The yield of seed cotton in maunds (1 maund=82.2 lbs.) per acre for each of the eight districts and for the province was then calculated.

There were various objections to this method of calculating the yields: (1) the figures for the number of bales pressed in each district may not be quite accurate; (2) the bales marked as American cottons contained varying proportions of *desi* cottons mixed with it and (3) a small fraction of seed cotton was always locally consumed and it was therefore not included in the number of bales pressed. It will be seen that even with such inaccuracies in the data, the reported failure years were characterised by great fall in the normal yields of each district and of the province as a whole.

(*i*) Variations in the Yields of Americans.

The yields in maunds per acre of American cottons for the eight districts and for the whole province for the years 1921—1935 are given in Table 1.

Taking the province as a whole the yields were reduced to 3.18, 3.28 and 3.14 maunds per acre for the three failure years 1921, 1926 and 1928 respectively. These years were reported to be the worst years for American cottons in the Punjab. Similarly the yields were low in 1927, 1931 and 1932 fluctuating between 4.5 to 4.7 maunds per acre. The yields were normal in 1922, 1925, 1929 and 1930 and very good in the remaining years. The average yields of the whole province were lowered by 39.5%, 37.6% and 40.3% of the general mean in the years 1921, 1926 and 1928 respectively and by 10% to 18% in 1927, 1931 and 1932.

When the yields of the different districts were separately studied, it was seen that in all the eight districts (with the exception of Gujrat district in 1921) the yields were low in the three years 1921, 1926 and 1928. The extent to which the yields were lowered in each district during these years varied from district to district. In 1921 the yields were lowered by 20% to 58% of the general mean in each of the seven districts. Similar variations in the depression in yields expressed as percentages of the general means were found in 1926 and 1928. In 1932, with the exception of Gujranwala district, the yields were below average in all the districts, while in 1931 the yields were below average in all the districts, except in Lyallpur and Montgomery districts. Similarly Gujrat, Gujranwala and Shahpur districts had normal yields in 1927, while the yields in the remaining districts in the same year were below normal.

Thus in the whole province the crop was bad in 1921, 1926 and 1928, partially bad in 1927, 1931 and 1932, normal in 1922, 1925 1929 and 1930 and very good in 1923, 1924, 1933, 1934 and 1935. It thus became quite clear that 1921, 1926 and 1928 were the worst crop years, while 1927, 1931 and 1932 were partially bad years for American cottons in the Punjab. The yields of the districts taken separately showed that they were very low in the three years, *viz.*, 1921, 1926 and 1928, with one exception only, in all the districts. In the years 1927, 1931 and 1932 the yields were depressed in some districts but not in others.

Table I

Yields of seed cotton (Americans) in maunds per acre in the eight districts and in the whole province (1921—1935)

Districts.	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Average of 15 years.
1. Gujrat	5.99	5.98	5.51	6.75	5.75	2.51	6.48	3.74	5.48	5.20	3.74	4.47	4.94	7.59	6.69	5.39
2. Gujranwala	3.50	3.69	3.52	3.81	4.51	2.03	5.47	3.49	5.04	4.55	3.63	4.94	4.25	6.69	6.58	4.38
3. Shahpur	3.00	5.00	6.00	5.84	3.99	2.00	6.00	2.75	3.00	3.94	3.75	3.75	5.97	8.19	7.06	4.68
4. Sheikhupura	3.50	4.98	6.99	7.78	5.49	3.50	5.00	3.50	5.48	5.24	4.49	5.00	6.45	7.72	8.37	5.57
5. Lyallpur	2.50	5.99	7.00	7.30	6.50	3.94	5.00	3.25	6.00	5.99	6.01	5.51	7.50	8.75	9.50	6.05
6. Montgomery	3.00	5.01	7.00	5.84	5.00	3.24	4.01	3.00	6.51	6.50	5.25	5.00	10.01	7.25	9.00	5.71
7. Jhang	2.50	4.51	6.00	4.85	3.99	3.98	3.99	2.74	3.99	4.99	3.98	3.50	6.25	5.98	6.47	4.51
8. Multan	3.00	4.23	4.99	5.34	4.00	3.50	3.01	2.75	4.00	4.50	4.00	4.01	7.00	8.25	7.50	4.67
Average of the eight districts	3.37	4.92	5.88	5.94	4.90	3.09	4.87	3.15	4.94	5.11	4.36	4.52	6.55	7.55	7.65	5.12
Average of the whole province	3.18	5.00	6.32	6.10	5.06	3.28	4.73	3.14	4.99	5.22	4.56	4.53	7.30	7.67	7.86	5.26

A fall in yield of about two maunds per acre in each of the three failure years in the province as a whole meant a great financial loss to the cotton growers and a loss in revenue to the Government of the province as well. If the average total acreage under the American cottons in the Punjab was taken as one milion and if the price of seed cotton per maund was taken at its lowest value of Rs. 7 per maund, the total loss in a year like one of these failure years, would amount to 1.4 crores of rupees. It was, therefore, a matter of great importance that the causes of such failures of American cotton crops in the Punjab should be immediately investigated and if possible be remedied.

(*ii*) VARIATIONS IN YIELDS OF *Desis*.

It had been stated that *desi* cottons did not suffer in yields to a great extent in these failure years and the term failure was used for the low yields of American cottons which exhibited the symptoms of '*tirak*.' The yields of *desi* cottons were, therefore, collected to see the depressions in their yields during the same years.

The results of the yields, in maunds per acre, for *desis* during 1921-1935 are given in Table II. Taking the province as a whole the yields had fluctuated from 2.89 to 5.57 maunds per acre during the 15 years, the general mean yield being 4.05 maunds. Thus the yields of *desi* were, on the whole, lower by nearly 1.2 maunds than the yields of Americans. The low yields of *desis*, as compared with Americans, may be due to the fact that Americans were generally grown on fertile lands while *desis* were grown on poor lands.

The results showed that *desi* and American crops were good, normal or bad in the same years. Both Americans and *desis* failed in 1926 and 1928, were good in 1924, 1933, 1934 and 1935 and normal in 1925, 1929 and 1930. In 1931 *desis* suffered more than Americans and in 1921 and 1927 Americans suffered more than *desis*. The general conclusion is that in most of the years *desi* and American crops have been good, normal or bad. In some years there were small differences in the percentage deviations from the respective mean yields and this was quite natural as even amongst Americans or *desis* themselves such differences in the yields between the different districts in the same year did exist. Thus the only difference between the failures of American and *desi* cottons was that *desi* plants did not exhibit externally the symptoms of *tirak*, *viz*., the early yellowing and shedding of the leaves and the bad opening of the bolls. This was a very important point to be considered. The yields of seed cotton may be lowered when *tirak* occurred on account of a reduction in the boll weight but the yield of seed cotton may also be lowered if the number of bolls per plant was reduced. In the reports of Milne (1922, 1928) and Trought (1931) the early yellowing and shedding of leaves and the 'bad opening' of bolls had been reported to occur in American cottons in the failure years but no mention was made of simil r symptoms developing in *desi* cottons even though the yields of *desi* cottons were lowered as shown in the Table II. The low yields in *desi* cottons may therefore be due to a reduction in bearing in the failure years. As the decrease in boll number in American cottons had not been reported to occur in the failure years, the low yields may be wholly due to a decrease in boll weight (*i.e.* weight of seed cotton per boll). It is possible that *desi* plants were physiologically different from the American cotton plants and therefore such symptoms did not develop in the former.

TABLE II

Yields of seed cotton (desi) in maunds per acre in the eight districts and in the whole province (1921—1935)

Districts.	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	Average of 15 years.
1. Gujrat	3.38	4.50	3.77	3.56	3.88	2.46	3.79	3.00	4.52	4.36	2.68	3.51	4.87	6.11	4.55	3.93
2. Gujranwala	3.43	2.97	2.51	3.72	3.41	2.14	4.27	2.55	3.84	3.84	1.93	4.01	4.48	4.43	4.90	3.50
3. Shahpur	2.98	3.83	4.46	3.16	2.84	2.33	4.17	2.33	3.40	4.12	2.12	2.97	4.58	6.34	4.81	3.63
4. Sheikhupura	3.43	2.56	4.29	5.79	4.24	2.97	4.30	2.78	5.15	3.85	2.55	3.62	5.70	6.54	6.18	4.26
5. Lyallpur	3.00	3.43	5.25	6.25	5.15	4.35	3.42	3.00	5.36	4.28	3.43	4.29	7.72	6.22	7.07	4.81
6. Montgomery	3.45	5.15	6.00	4.98	4.28	3.00	3.43	2.14	5.15	5.14	2.79	4.07	6.88	5.79	6.86	4.60
7. Jhang	3.00	2.56	4.23	4.18	3.81	4.11	3.35	2.12	2.81	3.52	2.67	2.47	5.27	4.26	4.61	3.53
8. Multan	3.42	3.43	3.85	3.74	3.22	3.00	2.58	2.13	3.00	3.42	2.14	2.99	4.71	5.35	4.69	3.44
Average of the eight districts	3.26	3.55	4.28	4.42	3.85	3.05	3.66	2.51	4.15	4.07	2.54	3.49	5.52	5.63	5.46	3.96
Average of the whole province	3.63	3.75	4.05	4.41	3.86	2.89	3.75	3.03	4.48	4.16	3.22	4.22	4.77	5.06	5.57	4.05

(*iii*) Correlation Studies of the Yield data

The foregoing yield data relating to American and *desi* cottons during the 15 years were statistically analysed to see how far the general conclusions reached above were supported.

The correlational analysis of the yields of American and *desi* cottons showed that there was a highly significant correlation between *desi* and American yields in all the eight important districts, the values of correlation coefficients ranging from +0.7248 to +0.9147. This supported the general conclusion that *desi* cottons did badly or well in the years in which American cottons failed or gave high yields (Table III).

The correlation of the yield of American cottons with time was significant or suggestive in case of the majority of districts (Table III) varying from +0.6426 to +0.0118, while the correlation coefficients of the yields of *desi* with time were also significant or suggestive, the value varying from + 0.5060 to +0.2569. The pooled correlation co-efficients were, however, highly significant both for *desis* ($r= +0.4041$) and Americans ($r= +0.4635$). Thus there was an indication of a steady rise in the yields of American and *desi* cottons.

Table III

Districts	*Desi* Cottons			American Cottons			*Desi* & American correlation
	Mean	Successive year correlation	Correlation with time	Mean	Successive year correlation	Correlation with time	
Gujrat	3.929	+0.2379	+0.4132	5.388	−0.0408	+0.0118	+0.7248
Gujranwala	3.495	−0.0141	+0 5060	4.380	+0.0877	+0.6426	+0.8248
Sheikhupura	1.263	+0.3650	+0.4663	5.566	+0.5180	+0 3791	+0.8643
Shahpur	3.629	+0.3055	+0 3960	4.683	+0.3662	+0.3537	+0.8657
Layllpur	4.807	+0.4576	+0.5020	6.049	+0 5283	+0.5437	+0.8191
Montgomery	4.605	+0.3496	+0.3298	5.708	+0.3843	+0.5933	+0.9138
Jhang	3.531	+0.1765	+0 2569	4.515	+0.3952	+0.4476	+0.8006
Multan	3.445	+0.6438	+0.3423	4.672	+0.7610	+0.6030	+0.9147
Pooled correlation		+0.3285	+0.4041		+0.4026	+0.4635	..
		n = 89	n = 97		n = 89	n = 97	..

The successive year correlation in the case of *desi* and American cottons came out to be significant in the case of one district (Multan) while suggestive in the case of a few others (Table III). The pooled correlation coefficients for both were highly significant ($r= +0.3285$ for *desi* and $r= +0.4026$ for Americans). Thus there was a tendency for low yielding and high yielding years to be associated together in groups; 1919, 1920 and 1921 ; 1926, 1927 and 1928; and 1931 and 1932 were low yielding years while 1923 and 1924 and 1933, 1934 and 1935 were high yielding years. The yields of American and *desi* cottons had gone up during the last three years, and this conspicuous increase in the yields of both cottons since 1933 had in all cases considerably increased the regression of yield on time.

Fig. 1 Section of a leaf of 4F Punjab-American Cotton (G. hirsutum) showing normal chloroplasts.

Fig. 2 Section of a leaf of 4F Punjab-American Cotton showing large starch grains (unstained) inside the chloroplasts which have bulged out and joined with one another.

CHAPTER III

TIRAK ON LIGHT SANDY SOILS DEFICIENT IN NITROGEN

Two lines of work were undertaken during the first two years of the investigations on the causes of *tirak* in the Punjab-American cottons. (1) Detailed observations were made on the cotton crop at all stages of development with a view to find out plants exhibiting the symptoms of *tirak* and to continue these observations in the same areas during the second year. (2) If a disturbance in the mineral uptake was the cause of *tirak*, it would be possible to detect by microchemical tests and by microscopical examinations some abnormality in the tissues of the roots, stems and leaves of plants that later developed the external symptoms of the 'disease.' It can be now said that the knowledge that has been gained on this complex problem of *tirak* and on the problem of cotton failures in the Punjab had its beginning in the preliminary observations made on the two lines of work mentioned above. These two lines of work showed that (1) there were abnormalities in the tissues of the leaves of plants that suffered from *tirak* and (2) *tirak* occurred even in normal crop years and it was found to be present, in some cases, in the same field or on the same patch of a field whenever cotton was grown there.

In order to follow the sequence of changes occurring in the crop that developed symptoms of *tirak* it was necessary at the outset to state that there were two types of soils where *tirak* symptoms developed.

The two types of soils associated with *tirak* were found to be (1) light sandy soils deficient in nitrogen and (2) soils which contained free sodium salts or sodium clay or both together in the subsoil beginning from the 3rd or the 4th foot from the soil surface. The nature of the physiological disorder which led to the development of *tirak*-affected crop was found to be different on the two soil types. The popular name *tirak* was, however, retained here for the 'disease' appearing on either of the two types of soils. In this Chapter the investigations dealing with the development and causes of *tirak* on light sandy soils are described.

(*i*) Abnormal features inside the leaves

An accumulation of starch in the mesophyll cells of the leaves was the first noticeable abnormal feature. The leaves at dawn were found gorged with big starch grains (Dastur 1939a). This condition was found to occur as early as July or later according to the degree of nitrogen deficiency in the plant. The starch grains formed in the chloroplasts during the day did not get dissolved at night as they did in the leaves of normal plants (Fig. 1) but they daily grew bigger and bigger in size on account of the deposition of fresh starch layers during the day (Fig.2) The chloroplasts got bulged and were reduced to a thin membrane covering the big starch grains. In some cases, the starch grains were found to rupture the chloroplasts, and the ruptured membranes of the chloroplasts could be distinguished by proper staining.

The accumulation of a substance giving the reactions of a "tannin" in the palisade and spongy cells of the leaves was another abnormal feature of plants

growing on this type of soil (Fig. 3.) Many a time "tannin" appeared in cells which contained the starch grains. The probable chemical nature of this substance was established first by microchemical and later by macrochemical methods (Dastur, 1939 b).

The accumulation of "tannin"* in the leaves was found to occur much earlier than the appearance of *tirak* symptoms. The accumulation of "tannin" began to occur in the leaves at the beginning of the flowering stage, *i.e.*, in August while *tirak* symptoms appeared in October. No such accumulation of "tannin" was found to occur in the leaves of normal plants up till the end of October.

Between these two extremes there were found plants in which a certain amount of accumulation of the substance in the leaves occurred during the fruiting period.

The relation between these three internal symptoms : (1) the accumulation of starch, (2) the mechanical breakdown of the chloroplasts and (3) the accumulation of "tannin" in leaves and *tirak* was finally established by a systematic investigation of the leaves during the growth of the plants in fields known to be deficient in nitrogen and in fields where no nitrogen deficiency was known to occur.

(*ii*) Relation between "Tannin" Accumulation and Nitrogen Content

During the cotton season of 1937-38 the leaves of 4F cotton plants from a manurial experiment were examined periodically for "tannin" from the month of July onwards. The fertilizers used were all combinations of ammonium sulphate, potash and superphosphate. The results of this investigation showed that there was a great accumulation of "tannin" in the leaves of plants grown on the control plots and on plots that had been manured with potash or surperphosphate, while there was little or no accumulation of "tannin" in the leaves of plants on plots that had received ammonium sulphate, either singly or in combination with potash or superphosphate or both. In fact, in many of the latter cases the leaves were found to be free from "tannin." "Tannin" was found to accumulate from the third week of August in the leaves from plots to which nitrogen had not been applied. There was thus a marked difference between the leaves of plants from the nitrogen and no-nitrogen plots, when examined microchemically.

The results stated above suggested some relationship between "tannin" accumulation in leaves and their nitrogen contents. This possible relationship was, therefore, investigated during the next cotton season. A chemical method for testing "tannin" was developed to replace the microscopic method (Fig. 4). This method is described in detail in Chapter X.

In the cotton season of 1938-39 two manurial experiments were laid out. In the first experiment 50 lb. of nitrogen in the form of ammonium sulphate was applied either (1) at sowing time or (2) at flowering time or (3) at both stages. Control plots were also included. In a second experiment in the same square (1) sulphate of of ammonia and (2) green manuring were among the treatments. The leaves of plants from the nitrogen and no-nitrogen plots were tested for "tannin."

The positive "tannin" test was again given at the flowering phase by the leaves of plants grown in plots to which no nitrogen had been applied, while the test was not given at the same stage by leaves of plants from plots treated with nitrogenous fertilizers as shown below in Table IV.

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* This substance giving the reactions of a tannin is provisionally named as tannin.

FIG. 3. Section of leaf of 4F Punjab-American Cotton plant showing thick "tannin" deposits in the palisade and spongy cells.

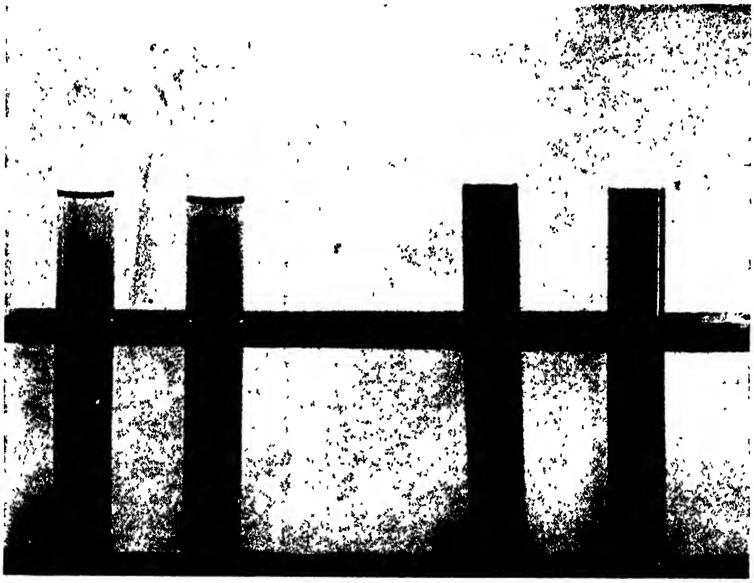

FIG. 4. Negative (left) and positive (right) tests of "tannins" in extracts of leaves with a high (3.53%) and a low (2.14%) nitrogen content respectively.

TABLE IV

Effect of nitrogenous fertilizers on the accumulation of "tannin" in leaves (two replicates).

TREATMENT	DATES				
	9-9-38	21-9-38	29-9-38	7-10-38	10-10-38
Control	+	+	+	+	+
Green manure	—	—	—	—	—
50 lb. N. as sulphate of ammonia at sowing	—	—	—	—	+
50lb. N. as sulphate of ammonia at sowing	—	—	—	—	+
50 lb. as sulphate of ammonia at flowering	—	—	—	—	+
50 lb. N. at sowing + 50 lb. N. at flowering as sulphate of ammonia	—	—	—	—	—

It was evident from the results that the nitrogen metabolism of the plant had some relation with the accumulation of "tannin" in leaves. Steps were, therefore, taken to determine the nitrogen contents of the leaves of plants grown in the control plots and of the leaves of plants from plots treated with sulphate of ammonia. The leaves of five plants selected at random from each plot were collected at fortnightly inervals and their nitrogen contents determined by the kjeldahl's method. The leaves after drying were also tested for "tannin".

The total nitrogen contents of the leaves of plants from the control plots were found to be at a lower level than the total nitrogen contents of the leaves of plants at the same stage of growth from plots that had received ammonium sulphate. The total nitrogen content of the leaves of the control plots was on an average 1.76% of the dry matter on 20th September when "tannin" was found in them while it was maintained at a higher level in the leaves of plants from the manured plots (Table V).

The positive test for "tannin" was given by the leaves when the total nitrogen of the leaves fell in the neighbourhood of 2.5 per cent. while the test was negative when the total nitrogen of the leaves was higher than 2.5 per cent (Tables V and VI). The leaves of the control plots gave a positive "tannin" test early in September, and this was accompanied with a low nitrogen level in the leaves. The negative test was generally accompanied with a high nitrogen level in the leaves (Fig. 4). The values

TABLE V

Total nitrogen content of the leaves with a positive or a negative test for "tannin"

Plot No.	26-8-38		20-9-38		20-10-38		Wt. of seed cotton per boll in gm.	Yield in lb. per plot.
	% of N.	"Tannin."	% of N.	"Tannin."	% of N.	"Tannin."		
				Control				
1	2.58	—	1.82	+	1.46	+	1.56	15.8
4	2.99	—	2.26	+	1.62	+	1.55	13.1
16	2.54	—	1.71	+	1.57	+	2.06	15.6
20	2.82	—	1.65	+	1.22	+	1.85	18.8
39	1.97	+	1.51	+	1.23	+	1.61	16.6
50	2.42	+	1.71	+	1.15	+	1.84	16.3
62	2.52	—	1.71	+	1.31	+	1.31	15.4
Mean	2.55		1.76		1.36		1.68	15.9
				50 *lb. Nitrogen at sowing time* (16-5-38)				
18	3.34	—	3.15	—	2.32	+	2.15	31.0
13	3.22	—	2.81	—	2.31	+	1.83	25.6
49	—	—	2.65	—	1.85	+	2.44	35.5
32	2.69	—	2.20	+	1.75	+	2.16	36.2
45	—	—	2.69	—	1.70	+	2.21	32.3
59	3.46	—	2.67	—	1.98	+	2.36	31.0
52	2.98	—	2.66	+	2.03	+	2.22	32.6
64	3.27	—	2.85	—	2.01	+	2.31	35.3
Mean	3.16		2.71		1.99		2.21	32.4
				50 *lb. Nitrogen at flowering* (17-8-38)				
8	2.96	—	2.43	+	2.07	+	1.86	25.3
19	2.69	—	2.63	+	2.00	+	1.96	27.4
26	2.69	—	2.74	—	2.30	+	2.47	34.00
38	2.27	—	2.52	—	1.81	+	2.16	31.4
37	2.55	+	2.41	+	1.47	+	1.98	31.8
53	2.51	—	2.46	—	1.84	+	2.26	29.3
63	2.94	—	2.74	—	2.01	+	2.55	32.3
58	3.01	—	2.63	—	1.79	+	2.15	29.3
Mean	2.70		2.57		1.91		2.17	30.1
				50 *lb. Nitrogen at sowing* + 50 *lb. Nitrogen at flowering*				
28	2.71	—	3.24	—	2.68	—	2.52	38.8
15	3.18	—	3.24	—	2.77	—	2.04	25.7
42	2.98	—	3.04	—	2.51	—	2.29	37.9
57	3.28	—	2.97	—	2.38	—	2.50	34.5
60	3.15	—	3.21	—	2.40	+	2.44	39.9
40	—	—	3.21	—	2.38	+	2.52	37.6
56	3.17	—	2.96	—	2.40	+	2.32	39.9
35	3.32	—	3.10	—	2.42	+	2.34	37.4
Mean	3.11		3.11		2.49		2.37	36.4

of the total nitrogen in the leaves giving a positive test was slightly higher than 2.5 per cent. in some determinations, as can be seen from Table V, but such results were not unexpected as the leaf material was composed of all leaves, young and old, from five plants from the field. If the leaves of one of the five plants contained "tannin" and a low nitrogen content, and if the leaves of the remaining four plants contained a high nitrogen content and no "tannin," the "tannin" reaction, which was a colour reaction, may be given but the average value of the total nitrogen may come out higher than 2.5 per cent.

In Table V the yields of plots under different treatments are given alongside the nitrogen contents and a positive or a negative "tannin" reaction. It will be seen that the yields of the control plots were lower than the yields of plots treated with nitrogen. The addition of sulphate of ammonia had thus a marked effect on the yields of seed cotton.

The weight of seed cotton per boll was also found to increase as a result of the application of ammonium sulphate. The weight of seed cotton per boll which has been employed as a quantitative measure for estimating the intensity of *tirak* or 'bad opening' was determined by weighing the seed cotton of bolls of five plants each, in two separate units from each plot. The weight of seed cotton per boll was higher in plants treated with sulphate of ammonia than in the case of plants in the control plots. There was thus an increase in the maturity of seeds and consequently a great improvement in the 'opening of bolls' on account of nitrogen application.

The relationship of "tannin" to nitrogen deficiency was again confirmed in the cotton season of 1939-40 by analysing the leaves from the nitrogen and no-nitrogen plots in a field experiment. "Tannin" tests were made in three replicates of the control plots and of plots that had received 50 lb. N. as sulphate of ammonia on 14th August, 1939. Three sowing dates were included in the experiment to determine the relation of sowing time with the appearance of "tannin" and *tirak* symptoms. The "tannin" reaction was first given by the leaves of plants from the control plots sown on 12th May, at a later date by the leaves of plants from the control plots sown on 2nd June and still later by the leaves of plants of the control plots sown on 22nd June. Thus by delaying sowings the accumulation of "tannin" in leaves was also delayed.

The leaves of plants in plots treated with sulphate of ammonia under the three sowing dates did not give a positive test for "tannin" up till 20th October (Table VI) when the "tannin" reaction was generally given even by all cotton plants which did not suffer from *tirak*.

TABLE VI

Total nitrogen contents and the "tannin" reactions of the leaves of plants from nitrogen treated and control plots

Sowing date.	Control Plots.								Nitrogen Plots (50 lb. N. on 14-8-39).							
	21-8-39		10-9-39		30-9-39		20-10-39		21-8-39		10-9-39		30-9-39		20-10-39	
	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."	% N.	"Tannin."
12-5-39	2.14	+	1.63	+	1.50	+	1.31	+	2.47	—	2.84	—	2.12	+	1 76	+
2-6-39	2.20	+	1.73	+	1.60	+	1.32	+	2.67	—	3.04	—	2.52	—	2.11	+
22-6-39	2.98	—	2.39	+	1.97	+	1.81	+	3.53	—	3.33	—	3.32	—	2.70	—

The nitrogen contents of the leaves of plants in one replicate of the above experiment were determined (Table VI). The leaves of five plants in each plot were dried in order to determine total nitrogen as was done in the previous year. "Tannin" tests were also made from the same samples.

The results showed that the nitrogen contents of the leaves in the control plots were at a lower level than those of the leaves in the plots treated with sulphate of ammonia. As the sowing date advanced the nitrogen content of the leaves showed an increase at each date when the determinations were made. This held good both for the leaves from the control as well as from nitrogen treated plots.

The yields of seed cotton in lb. for each plot and the weight of seed cotton in gm. per boll under the three sowing dates with and without nitrogen are given in Table VII.

In the control plots the weight of seed cotton per boll improved as the sowings were delayed. The third sowing produced as high a maturity of seed in the absence of nitrogen as in its presence. In the first two sowings the application of nitrogen had increased the weight of seed cotton per boll. Thus *tirak* was remedied on light sandy soils either by the application of nitrogen or by delaying sowings till late in June.

TABLE VII

Yield of seed cotton per plot in lb. and weight of seed cotton in grams per boll in nitrogen and no-nitrogen plots (1939-40)

Control				50 lb. N. at flowering			
Plot No.	Date of sowing	Wt. of seed cotton per boll in gm.	Yield per plot in lb.	Plot No.	Date of sowing	Wt. of seed cotton per boll in gm.	Yield per plot in lb.
8	12-5-39.	0.91	6.25	3	12-5-39.	1.48	17.2
42	,,	1.11	8.75	13	,,	1.49	18.5
38	,,	0.98	7.50	45	,,	1.77	18.0
	Mean	*1.00*	*7.50*		*Mean*	*1.58*	*17.9*
57	2-6-39.	1.36	9.10	16	2-6-39.	1.39	17.7
62	,,	1.14	8.90	29	,,	1.72	22.1
15	,,	1.16	8.50	50	,,	1.90	21.1
	Mean	*1.22*	*8.83*		*Mean*	*1.67*	*20.3*
10	22-6-39.	1.23	7.25	7	22-6-39.	1.55	12.3
49	,,	1.52	12.50	23	,,	1.15	11.8
71	,,	1.48	11.25	39	,,	1.75	16.9
	Mean	*1.41*	*10.3*		*Mean*	*1.48*	*13.6*

The yields from plots treated with sulphate of ammonia were higher than those from the control plots sown on the same date. The plots sown on 22-6-39 responded to a smaller extent to the application of sulphate of ammonia than in the other two cases. This was due to a reduction in the vegetative growth resulting in a decreased boll-production. The last-sown plots had, therefore, not profited by the application of the sulpate of ammonia to the same extent as the early-sown plots.

An examination of the sections of leaves under the microscope in the cotton season of 1937-38 showed that the accumulation of starch in the mesophyll cells preceded the accumulation of "tannin." It was also observed that there was very little accumulation of starch in leaves from the nitrogen plots, while starch and "tannin" were found in considerable amounts in the leaves of no-nitrogen plots. The starch contents of the leaves at dawn from some of the plots of the field experiment of 1938-39 were, therefore, determined, and it was found that while the starch content of the leaves of plants manured with sulphate of ammonia was negligible, the starch content of the leaves from the unmanured plots varied from 2 to 6 per cent. of the dry matter.

(*iii*) The Relation between "Tannin" Accumulation and other Minerals

The accumulation of starch and "tannin" in leaves may not be a direct result of a nitrogen deficiency. These accumulations may be due to a deficiency of some mineral which was not absorbed by the plant in the required amounts as a result of shortage of nitrates in the soils. It is a well-known fact that the absorption of one ion was governed, amongst many other factors, by the availability of another ion. When nitrogen was added to the soil, other ions might have been absorbed in increasing or decreasing proportions, thus resulting in the non-accumulation of starch or "tannin" in the leaves. It was mentioned before that the addition of superphosphate and potash to such soils did not either lessen the accumulation of starch and "tannin" in leaves or increase the yields. The deficiency of these minerals in the soil was therefore not indicated. It was possible, however, that their absorption was limited by the low level of nitrates in the soils.

In order to investigate this point, nitrogen, potash, phosphoric acid and lime contents of the leaves giving positive and negative reactions for "tannin," *i.e.*, of the leaves of plants from the control plots and from the plots manured with sulphate of ammonia were determined. The results are stated in Table VIII.

Table VIII

Mineral analysis of leaves giving a positive and negative test for "tannin" (percentage expressed on dry matter)

Treatment	24th September				20th October			
	Nitrogen	Potash	Phosphoric acid	Lime	Nitrogen	Potash	Phosphoric acid	Lime
Control	1.71	4.28	0.421	4.81	1.31	3.16	0.310	4.38
50 lb. N. at sowing time ..	2.85	4.82	0.481	5.32	2.03	4.09	0.354	5.32
50 lb. N. at flowering stage ..	2.63	4.56	0.453	5.51	1.79	3.64	0.328	5.23
50 lb. N. + 50 lb. N. (at sowing & flowering stages).	2.98	4.58	0.482	5.32	2.38	4.18	0.356	5.26

A study of the results showed that the potash and lime contents of the leaves of plots treated with sulphate of ammonia were higher than those of the leaves of the control plots. There was thus an indication that the increased absorption of nitrogen by the plant was accompanied by an increased absorption of potash and lime. Similar trends were noticeable from analyses of leaves of plants made in the succeeding cotton seasons. It remained, therefore, unsettled whether a deficiency of nitrogen or a deficiency of other minerals due to their non-absorption in soils deficient in nitrogen was responsible for the observed accumulation of starch and "tannin" substances in the leaves.

The applications of potash, phosphorus or lime to light sandy soils were not found to improve either the opening of bolls or to increase the yields. The chemical analysis of the soils did not reveal any clear and constant differences between the potash, lime and phosphoric acid contents of the light sandy soils where *tirak* occurred and of normal soils where these symptoms did not develop.

The only conclusions that can be drawn are that the accumulation of "tannin" was found to begin when the nitrogen content of the leaves fell below a certain level and the accumulation of this substance could be prevented by applications of sulphate of ammonia. These conclusions held good only for 4F Punjab-American cotton. No such detailed study to determine the level of nitrogen in the leaves at which "tannin" began to accumulate had been made in the case of other commercial varieties of Punjab-American cottons, though the leaves of these cottons grown on light sandy soils gave the "tannin" reaction just like the leaves of 4F. The "tannin" reaction was also given by the leaves of *desi* cottons which did not suffer from *tirak*.

(*iv*) Relation between "Tannin" Accumulaton and Boll Production

The application of sulphate of ammonia to other Punjab-American strains like 289F/43, 289F/K25 and L.S.S., when the the "tannin" reaction was given by their leaves, were also found to prevent the development of *tirak*. The leaves of these strains remained green and healthy at the fruiting stage when the sulphate of ammonia was applied. The weight of seed cotton per boll increased, indicating better maturity of seeds, and high increases in yields were registered. In the case of *desi* cottons, which did not suffer from *tirak*, applications of the sulphate of ammonia after the leaves had given the "tannin" reaction were found to increase yields but they had no effect on the weight of seed cotton per boll (*i.e.*, boll weight).

The increase in the yields registered in Punjab-American cottons when sulphate of ammonia was applied to such light sandy soils was caused by an increase in the boll weight (*i.e.*, weight of seed cotton per boll) as well as by an increase in boll number. Thus the prevention of "tannin" accumulation by the addition of nitrogen was associated with a better maturity of seeds and a greater boll production. More and more evidence accumulated, as work progressed, to show that "tannin" accumulation in leaves was associated with a reduction in boll number per plant rather than with the decrease in maturity of seeds, *i.e.*, in boll weight. The application of nitrogen prevented the development of "tannin" in leaves and increased the meristematic activity of the plant which manifested itself in an increase in the number of nodes, flowers and bolls but they did not produce any effect on the boll weight. The evidences to substantiate these results are enumerated below:—

(1) The applications of sulphate of ammonia when "tannin" reaction was given by the leaves of *desi* cotton, produced an increase in boll number which

alone was responsible for the increase in yields as there was no effect on the boll weight. The bolls of this cotton did not show any immaturity of seeds on light sandy soils.

(2) The light sandy fields where the above-mentioned experiments were carried out contained portions which had sodium clay or free soluble sodium salts in the subsoil. The "tannin" reaction was given by the leaves of the 4F cotton plants that had come on such patches. Application of sulphate of ammonia to such patches had increased the nitrogen contents of the leaves which did not give the "tannin" reaction. There was also an increase in boll number per plant. There was, however, no increase in the maturity of seeds, *i.e.*, there was no improvement in the boll weight.

The salinity in the subsoil, as would be shown in Chapter V, was also found to be associated with immaturity of seeds, *i.e.* *tirak* and it was found that it could not be remedied by application of nitrogen. Thus there was some direct relation between nitrogen content, "tannin" reaction and the meristematic activity in the cotton plant while the relation between the nitrogen application and better seed maturity on light sandy soils free from sodium salts appeared to be an indirect one. It will be shown in Chapter VII, that immaturity of seeds was associated with the low potash contents in the leaves and bolls of *tirak*-affected plants on both types of soil and an increased uptake of potash by the plants treated with nitrogen on light sandy soils (Table VIII) was causing better maturity of seeds.

(3) If the Tables VI and VII were closely studied it would be found that the application of nitrogen to the crop sown on 22nd June had increased the nitrogen contents of the leaves but it had not further increased the weight of seed cotton per boll which was nearly the same as the weight of seed cotton per boll on plants sown on the same date but where nitrogen was not applied. Though the "tannin" reaction was given by the leaves of plants in the untreated plots, the weight of seed cotton per boll was as high as in the case of plants sown on 12th May and 2nd June and treated with 50 lbs. of nitrogen. Better maturity of seeds had occurred even when the "tannin" reaction was given by the leaves of 22nd June-sown crop. There was an increase in boll number in the crop sown on 22nd June in the presence of nitrogen but there was no further increase in the boll weight. Thus nitrogen application in the crop sown on 22nd June increased the nitrogen contents of leaves, prevented accumulations of "tannin" and increased the boll production but did not further increase the maturity of seeds.

The following are, therefore, the main conclusions arrived at so far. The "tannin" reaction was given by the leaves when the nitrogen contents fell below a certain level. This was accompanied by low meristematic activity. Applications of nitrogen prevented the accumulation of "tannin" in leaves, increased the level of nitrogen and other minerals, prolonged the meristematic activity of the plant which produced more flowers and bolls. The maturity of seeds appeared to be unaffected in the presence of "tannin."

The relation of "tannin" with reduced bolling appears to have a great bearing on the growth of cottons in general. Very preliminary work has revealed that the "tannin" reaction that was given by the leaves was not a special feature of cottons growing on light sandy soils in the Punjab. "Tannin" accumulations have been found to occur in other cotton varieties and in cotton plants grown on other types of soils like the black cotton soils. In fact the cottons in other parts of India gave very

heavy reactions for "tannin." Such heavy "tannin" reactions were not even given by the leaves of Punjab-American cottons in the Punjab.

The leaves of different strains of upland cottons grown at different places in India were found to give the "tannin" reaction. The accumulation of "tannin" in the mesophyll cells was confirmed by microscopic examination of the leaves. The green leaves as well as the leaves which had changed their colour to brown and red gave the test. The leaves of upland cottons grown in Central India were found to give the "tannin" reaction when the plants were only few weeks old. The cotton plants in this area produce a small vegetative structure about 1 ft. to 1½ ft. in height. In all these cases immaturity of seeds in the bolls is not reported to occur.

From the results discussed above and the numerous observations made on the crop, it is at present surmised that the accumulation of "tannin" in leaves gradually depresses the functional activities of the leaves, which later cease functioning and turn yellow and red. The depression in the functional activities of the leaves has an adverse effect on fruiting which is reduced. When the "tannin" accumulations in the leaves start at a very early stage, the vegetative growth is also affected. These conclusions are only tentative and require confirmation by further work.

The low nitrogen content in 4F Punjab-American cotton was only one instance where "tannin" accumulation was found to be associated with another internal factor. The causes leading to such accumulations in other cottons in other tracts might be quite different. The important point is that once this substance accumulates in leaves, it very likely puts out of gear the metabolic machinery of the plant, resulting either in boll shedding or low bearing or leaf reddening or in some cases the suppression in growth. It is, therefore, necessary to investigate the causes that eventually lead to formation and accumulation of "tannin" in leaves in different cottons grown under different soil and climatic conditions and to determine the effect it has on the growth, bearing and yield of the cotton plant.

(*v*) Chemical Nature of the Substance giving "Tannin" Reaction

The chemical nature of the substance tentatively referred to as "tannin" is not finally determined and attempts are at present made to do so. It is provisionally called " tannin" on account of the black colour it gives with osmic acid (Fig. 4). Mitchell (1924) has given this reaction as a specific test for tannin but it is now found that this is not so. All substances containing polyhydric phenolic groups and unsaturated substances are capable of reducing osmic acid to a black compound. It is also known that amino acids like tyrosine and leucine give osmic acid reaction (Meyer 1931). Tannins give this reaction as they contain polyhydric phenolic groups. The only confirmatory test for tannin is its property to tan. An aqueous extract of the leaves of cotton is able to tan but the intensity of tanning was not found to increase on concentrating the extract.

Further work has shown that two substances which are able to reduce the osmic acid and form coloured compounds are extracted with water from the leaves. One of them gives a green colour with osmic acid while the other gives a black colour. In the invsestigations described above the word "tannin" or the phrase "tannin" reaction refers to the second type of substance that gives black colour with osmic acid. The presence of this substance in the mesophyll cells of the leaves indicates the beginning of metabolic disorder. In the Punjab it is found to be associated with a low nitrogen content in the leaves.

Fig. 5 Photograph of a normal crop of 4F Punjab-American Cotton showing the erect and turgid condition of leaves in September.

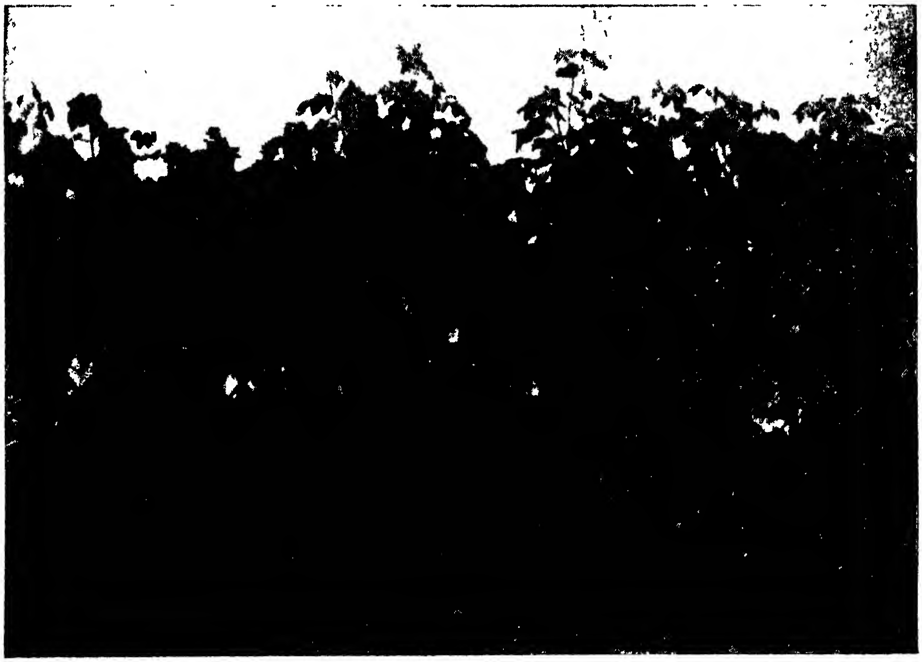

Fig. 6 Photograph of a crop of 4F Punjab-American Cotton on a soil with a saline subsoil showing the drooping of leaves in September.

CHAPTER IV

TIRAK ON SOILS WITH SALINE SUBSOIL

If the symptoms of *tirak* had been caused by nitrogen deficiency alone, on light sandy soils, the problem of determining the causes of *tirak* would not have turned out so very complicated. The problem of *tirak* was rendered complex as this disorder developed in the American cottons in the Punjab on account of two entirely different physiological causes of which one was nitrogen starvation and the other water starvation of the crop at the reproductive stage. This was an important instance where a plant produced immature seeds as a result of the physiological disorder developing in the plant on account of two different factors.

Even though there was great similarity in the symptoms of *tirak* produced on account of nitrogen starvation and water starvation, observations on the crops showed that there was a marked difference between the two cases in the external symptoms exhibited by the leaves. This difference was neither noticed nor described previously in any of the departmental reports or published articles on the subject. If that had been done, it would have been of great help in this investigation.

The distinguishing external symptom of the leaves growing on sandy loams which had subsoil salinity was the pronounced drooping of leaves in the months of September and October (Figs. 5 & 6). The leaves remained in drooping position throughout the day about one week after each irrigation. Irrigation temporarily revived the leaves but drooping position was assumed as soon as the upper surface of the soil lost its moisture. The leaves also turned dark and dull, lost fresh green and shining appearance and began to shed prematurely. *There was no yellowing of leaves prior to shedding as was the case with leaves suffering from nitrogen starvation.*

Microscopic examination of leaves did not show accumulation of starch as in the case of leaves from light sandy soils. On the contrary, the protoplasts of the cells had shrunk within the cells, showing loss of moisture from the vacuoles. There was no early accumulation of "tannins" in leaves of plants from some of these fields where a deficiency of nitrogen did not occur. The problem was thus complicated as the leaves of all *tirak*-affected plants did not show identical internal or external symptoms. The leaves of some *tirak*-affected plants showed large accumulations of "tannins" and starch while the leaves of other *tirak*-affected plants did not show such inclusions in the cells. In some cases of *tirak*-affected crop the leaves had turned yellow while no such yellowing of leaves occurred in other similarly affected crop.

Another complicating factor was the occurrence of both the types of soil conditions in the same field. The soils in such fields were light sandy deficient in nitrogen and the subsoil contained either sodium clay or free soluble sodium salts in the subsoil. In such cases the leaves turned copper or bronze coloured in September and October. They also contained starch and though the application of sulphate of ammonia to such fields prevented the accumulations of starch and "tannin " in the leaves which remained green at the time of fruiting, it did not increase the maturity of seeds. The main symptom of 'bad opening' of bolls was thus not remedied as in the case of *tirak* on light sandy soils deficient in nitrogen.

Tirak was thus caused by (1) nitrogen deficiency, (2) by water shortage at the fruiting stage, and (3) by both causes operating together in the same field. These causes had to be differentiated in the fields before a right understanding of the symptoms and the causes of *tirak* could be attained.

(*i*) Physical and Chemical Properties

(*a*) *Sandy loams with saline subsoil*

During the early stages of the soil investigation it was discovered that the soils where *tirak* appeared were alkaline in reaction varying from pH 9.2 to 9.8. The soils under normal plants were not so very alkaline in reactions, the pH fluctuating between 8.0 to 8.4 but such differences in the pH between the soils where normal and *tirak*-affected plants were observed, held good in some cases but not in others. The soil reaction was in the neighbourhood of pH 8.2 even when *tirak* was present (Table IX).

Later it was discovered that though the subsoil under *tirak*-affected crop was not alkaline there were present abnormal amounts of total soluble solids in such soils indicating the presence of neutral sodium salts (Table X). This led to the determinations of total soluble solids in the soils from normal soils and from soils where *tirak* occurred (Table X). A complete analysis of the soluble salts, foot by foot, showed that the soils where *tirak* appeared had a subsoil with abnormal amounts of soluble chloride, sulphate and bicarbonates as compared with the quantities of these salts present in the subsoil where normal plants grew. The abnormal amounts of sulphates, chlorides and bicarbonates were present from either the 3rd or the 4th foot downwards. In some cases there were also present small amounts of sodium carbonate, while sodium carbonate was absent in other cases. This explained the fact that the subsoils under *tirak*-affected plants were more alkaline in reaction in some cases than the subsoils under normal plants but this difference did not hold in other cases.

The mechanical analysis of the soils under two types of plants showed that the sand fraction decreased while the clay and silt fractions increased in the subsoil from above downwards where *tirak* had occurred but that again was not found to be a common characteristic of the soil where *tirak*-affected crop occurred.

A field measuring about one acre was selected for an intensive study of the soil conditions as *tirak* was found to be present in patches in that field in the cotton season of 1936. The patches bearing *tirak*-affected plants and normal plants were found irregularly distributed over the whole area. The field was, therefore, divided into 48 small plots of 1/80 acre each and the soil samples were collected from these plots up to a depth of six feet. The soil samples were analysed for total soluble salts, physical structure, pH, and soluble and exchangeable calcium and sodium. The cotton was sown in these plots in 1938 season and detailed observations on the condition of the crop were made all throughout the season. It was found that the normal condition of the crop was generally associated with the absence of sodium salts and *tirak* condition with the presence of soluble sodium salts in the subsoil (Fig. 7). It was sometimes found that normal plants occurred in one portion of a plot while *tirak*-affected plants occurred in another part of the same plot. So, fresh soil samples were collected to see the condition of the soil under each type of crop and the above-mentioned relationship was found to exist. The intensity and the spread of *tirak* was also found to vary in these plots in different years. In cotton season of 1938 *tirak* appeared in a less intense form and was on a smaller area than in 1939. The reasons for this difference in the intensity and the spread of *tirak* in the same field in the two seasons are discussed in Chapter XI.

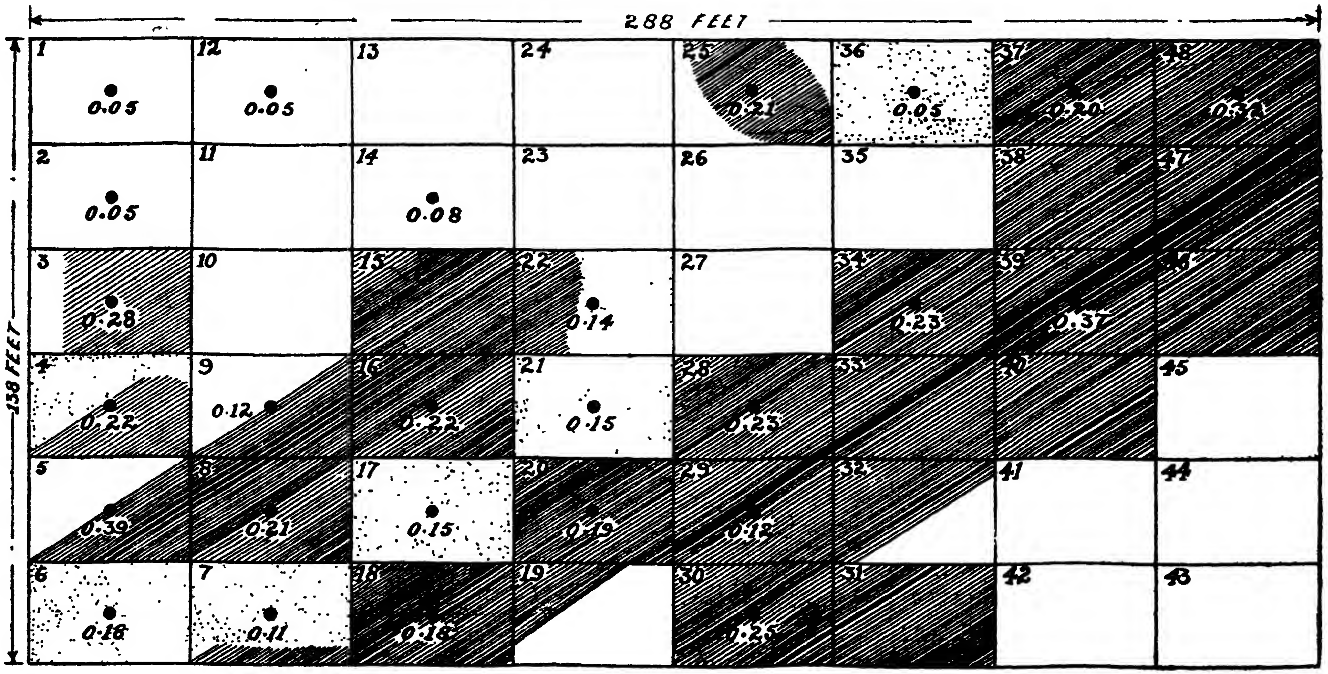

FIG. 7 Diagram showing the areas of subsoil salinity (shaded) in a field. The crops on these areas developed *tirak* symptoms, *viz.*, drooping and shedding of leaves and bad opening of bolls.

Black circles indicate spots where one foot soil samples upto a depth of 6 ft. were taken. Figures near them give percentages of total solids (average of lower 3 ft.). Shaded and dotted areas indicate portions of high and medium subsoil salinity while unshaded areas indicate normal non-saline portions.

TABLE IX.

Physical & Chemical properties of soil under normal and tirak-affected plants.

Depth in feet	Normal (sandy loam)					*Tirak* (sandy loam)					Normal (light sandy)					*Tirak* (sandy loam)				
	Clay %	Silt %	Sand %	Total solids %	pH	Clay %	Silt %	Sand %	Total solids %	pH	Clay %	Silt %	Sand %	Total solids %	pH	Clay %	Silt %	Sand %	Total solids %	pH
1	16	20	63	0.054	8.3	23	21	53	0.053	8.3	15	15	68	0.043	8.5	19	22	54	0.059	8.3
2	18	22	59	0.048	8.4	27	22	48	0.053	8.3	15	15	66	0.037	8.4	27	20	52	0.058	8.5
3	19	21	58	0.047	8.4	26	24	47	0.206	8.1	15	18	65	0.041	8.3	30	27	43	0.132	8.7
4	19	22	57	0.043	8.3	26	28	42	0.332	8.1	16	19	61	0.040	8.4	32	28	39	0.315	8.3
5	19	25	50	0.056	8.4	26	24	41	0.250	8.5	15	23	54	0.046	8.3	35	28	36	0.363	8.4
6	21	30	36	0.065	8.3	26	28	35	0.241	8.2	11	21	59	0.036	8.4	34	30	35	0.517	8 7
7	18	37	32	0.084	8.3	28	33	25	0.630	8.3	8	11	77	0.029	8.2	40	25	30	1.157	9 1
8	15	28	49	0.050	8.6	22	44	22	0.552	8.6	5	8	84	0.026	8.3	39	30	21	0.756	9.1
9	7	8	82	0.045	8.7	19	46	22	0.492	8.6	5	8	85	0.027	8.2	32	30	28	0.434	9.0
10	6	6	85	0.047	8.8	11	24	59	0.215	8.0	5	8	83	0.025	8.3	35	35	20	0.424	9.0
11	4	4	89	0.043	8.8	5	5	87	0.061	8.5	4	6	85	0.031	8.2	40	35	12	0.402	9.0
12	4	4	90	0.022	8.8	5	6	89	0.073	8.5	4	8	83	0.030	8.2	27	41	21	0.386	8.8

The above mentioned facts were again and again confirmed from fields in the different cotton growing districts in the Punjab where *tirak* was observed in the cotton seasons of 1937, 1938 and 1939. One foot soil samples upto a depth of six feet from Sarghoda, Montgomery, Multan and Lyallpur districts were collected where *tirak*-affected or normal crop was found to be present. From each *tirak*-affected patch which may vary in area from place to place, three to six bores were taken. On analysing the samples it was found that at some places the soils of all the three bores from a *tirak*-affected patch contained abnormal quantities of soluble sodium salts in the subsoil. From the results tabulated below it will be seen that the total soluble salts were above normal from either the 3rd, 4th or the 5th foot downwards (Table X).

TABLE X

Total soluble salts in the three bores of tirak-affected patches (in gm. per 100 grams of soil)

Depth in feet	Khanewal Bore No. I	Khanewal Bore No. II	Khanewal Bore No. III	Montgomery Bore No. I	Montgomery Bore No. II	Montgomery Bore No. III	Sargodha Bore No. I	Sargodha Bore No. II	Sargodha Bore No. III
1st ft.	0.049	0.044	0.046	0.057	0.060	0.044	0.064	0.067	0.088
2nd „	0.045	0.100	0.057	0.092	0.056	0.047	0.058	0.056	0.057
3rd „	0.049	0.146	0.052	0.154	0.382	0.059	0.147	0.082	0.074
4th „	0.140	0.135	0.083	0.175	0.439	0.066	0.235	0.061	0.081
5th „	0.479	0.140	0.156	0.513	0.303	0.056	0.304	0.154	0.109
6th „	0.310	0.160	0.306	0.444	0.229	0.054	0.242	0.175	0.288

It was also found that two bores out of three within a small *tirak*-affected patch of about 1/12 of an acre or less contained slightly more than normal quantities of soluble salts while the third bore contained abnormal amounts of total salts. This was an important fact which led to the understanding of the greater spread of *tirak* in certain years (failure years) than in others (normal crop years).

It was pointed above that when the soluble salts were high or abnormal they were preponderantly sodium salts while calcium salts were in smaller proportions than sodium salts. A large number of determinations of sodium and calcium were made in the water extracts of soils from *tirak*-affected and normal patches and in all cases soluble sodium was found to be in larger amounts than calcium (Table XI).

TABLE XI

Soluble calcium and sodium in soils under normal and tirak-affected crops

Depth in feet	*Tirak* Sol. sod. %	*Tirak* Sol. cal. %	Normal Sol. sod. %	Normal Sol. cal. %	*Tirak* Sol. sod. %	*Tirak* Sol. cal. %	Normal Sol. sod. %	Normal Sol. cal. %
1st ft.	0.004	0.006	0.003	0.011	0.004	0.009	0.004	0.009
2nd „	0.012	0.002	0.006	0.008	0.029	0.003	0.003	0.012
3rd „	0.042	0.003	0.006	0.010	0.084	0.003	0.002	0.010
4th „	0.065	0.003	0.007	0.010	0.152	0.008	0.002	0.010
5th „	0.106	0.003	0.006	0.010	0.126	0.008	0.003	0.009
6th „	0.125	0.003	0.008	0.010	0.130	0.004	0.006	0.016

A study of the exchangeable bases of soils of *tirak*-affected and normal patches revealed that in some cases the conversion of calcium clay to sodium clay in the subsoil of *tirak*-affected patches had occurred while it was not so in other cases even though soluble sodium was found to be in higher amounts than soluble calcium (Table XII). In the case of non-saline soils exchangeable sodium was nil or negligible and soluble salts were mostly calcium salts. It may be pointed out that in the following results the values of exchangeable sodium with potassium are given but separate determinations of exchangeable potassium revealed that it always fluctuated between 0.2 to 0.5 milliequivalents per 100 grams of soils in normal soils and in soils where *tirak* occurred. So when the combined value of exchangeable sodium and potassium was higher than 0.5 m.e. it was surmised that the remaining quantity represented exchangeable sodium alone.

TABLE XII

Soluble and exchangeable sodium and calcium in soils under tirak-affected and normal crops

(*a*) *Tirak*

Depth in feet.	Sargodha					Lyallpur				
	% total solids	% sol. Na.	% sol. Ca.	Exch'ble Na.+k m.e.	Exch'ble Ca. m.e.	% total solids	% sol. Na	% sol. Ca.	Exch'ble Na.+k m.e.	Exch'ble Ca. m.e.
1st foot ..	0 063	0.003	0.008	1.05	9.4	0 037	0.003	0.008	0.9	9 8
2nd ,, ..	0.058	0.008	0.007	0.88	11.2	0.076	0.029	0.006	1.1	11.6
3rd ,, ..	0.147	0.014	0.005	2.12	9.2	0.497	0.148	0.047	Nil.	11.2
4th ,, ..	0.235	0 059	0.004	3.00	7.21	0.583	0.155	0.039	,,	9 2
5th ,, ..	0 304	0 062	0.008	2.12	6.8	0.581	0.167	0.029	,,	7 8
6th ,, ..	0.242	0 060	0.005	1.35	6 0	0.375	0.148	0.013	4.2	5.6

(*b*) NORMAL

Depth in feet.	Sargodha					Montgomery				
1st foot ..	0.055	0.003	0.014	0.60	10.6	0.080	0 003	0.010	0.8	6.6
2nd ,, ..	0.063	0.003	0.012	0.48	12.4	0.098	0 002	0.009	0.8	7.0
3rd ,, ..	0.068	0 003	0.015	0.54	13.4	0.086	0.001	0.008	0.6	7.6
4th ,, .	0.058	0.003	0.013	0.65	13.4	0.094	0.002	0.009	0.4	8.4
5th ,, ..	0.067	0.004	0.015	0.48	12.6	0.098	0.001	0 008	0.6	8.4
6th ,, ..	0.067	0 003	0.013	0.43	10.3	0.094	0.001	0.008	0.6	7.2

* Exchangeable potassium is generally 0.2 to 0.5 m.e. per 100 grams of air dry soil.

The degree of sodiumisation of clay, *i.e.*, the amount of exchangeable sodium was not found to bear any relation to the total soluble sodium salts present. In many cases even though the total soluble sodium salts were very high the exchangeable sodium in the clay complex was low while the quantity of exchangeable sodium was high in soils containing lesser amounts of soluble sodium salts.

Thus the soils where *tirak* appeared were found to contain abnormal amounts of total soluble solids in the subsoil from the third or the fourth foot downwards. The soluble solids contained larger quantities of free sodium than calcium. In

some cases sodium had replaced calcium in the clay complex, while in other cases similar base exchange had not taken place even though free sodium was found to be in excess of calcium.

It was pointed above that (see Table X) out of three bores taken on a patch where *tirak* had occurred one bore showed abnormal amounts of total salts while the remaining two bores contained slightly more than the normal quantities of these salts. The total soluble salts were found to vary from 0.1% to 0.15% in all the layers of the soil. When these soil samples were further analysed it was found that even though the total salts were not abnormally high there were present larger amounts of soluble sodium than calcium (see Table XIII).

TABLE XIII

Soluble sodium and calcium in two soils of low sailnity in the subsoil

Depth in feet	Total soluble salts %	Soluble sodium %	Soluble calcium %	Total soluble salts %	Soluble sodium %	Soluble calcium %
1st foot	0.079	0.003	0.007	0.078	0.003	0.007
2nd ,, ...	0.073	0.003	0.007	0.066	0.003	0.006
3rd ,, ...	0.074	0.005	0.008	0.054	0.004	0.005
4th ,, ...	0.095	0.010	0.006	0.060	0.008	0.004
5th ,, ...	0.110	0.016	0.008	0.060	0.010	0.006
6th ,, ...	0.106	0.018	0.007	0.072	0.013	0.006

Joseph (1925), working on the soils in the Sudan had also reported the presence of high concentration of alkali salts in the 3rd and the 4th foot. The concentration of alkali salts which, according to him, consisted mostly of sulphates and carbonates was about 0.3% to 0.4% while in the first and the second foot it was less than 0.1%. The main differences between the soils in the Sudan and the soils in the Punjab were in their clay contents, and pH. The clay content in Sudan soils was shown to be about 55% and the pH about 9.3. The same author tried to show that the salt contents were inversely related to yields but an examination of his results did not justify that conclusion. Some of his 'high yield' plots showed high percentage of salts while some 'low yield' plots showed low percentage of salts. It was, therfore, likely that the soils in the Sudan were as heterogenous as they were in the Punjab and the soils with low and high salinity were intermixed.

The development of *tirak* on soils with saline subsoil was also found to depend on other soil conditions, the most important being the physical texture of the soil. High salinity in the subsoil in a light sandy soil produced the worst form of *tirak* as the toxic effect of sodium salts on the roots was very high under such conditions. In light sandy soils smaller amounts of sodium either in the soluble or exchangeable form were found to produce a *tirak*-affected crop while in heavier types of soils *tirak* did not occur under similar conditions (Dastur and Samant, 1942).

Similar observations have also been made by Harris (1915, 1920), Headley Curtis and Scofield (1916), Breazeale (1927), Harris and Pittman (1918), Hibbard (1925) and Kearney and Scofield (1936). Kearney and Scofield (1936) found 0.2% of total salts toxic to alfalfa in sandy soils while larger amounts were needed to produce toxic effects in loamy soils.

The toxic effect of sodium chloride on the growth of citrus trees has also been recorded by Hilgard (1906) and Neidig and Magnuson (1924). Theron (1937) found that sudden defoliation of citrus trees was caused by the presence of alkali salts in the soil. The deleterious effects exerted by these salts were due to their effect on the physical structure of the soil. Voelcker (1916) had also found that sodium chloride was most toxic to wheat when present in concentrations of more than 0.2%. It will be shown in Chapter VI that sodium chloride in high concentrations developed *tirak* symptoms in the cotton plant.

The salt tolerance of a plant was also influenced by temperature. Ahi and Powers (1938) have found that at high temperatures salts tolerance of grasses and legumes decreased while their resistance to salts increased at low temperatures. The relation between salinity, temperature and *tirak* in the American cottons in the Punjab is discussed in Chapter XI.

(*b*) LIGHT SANDY SOILS

The soils where the crops showed symptoms of nitrogen starvation were found to be light sandy contaning a large proportion of sand varying from 55 to 70%. The percentage of clay in such soils was found to vary from 8 to 12%. The subsoil was non-saline containing normal quantities of soluble salts which were mostly salts of calcium, while sodium was present in negligible amounts either in the free or the exchangeable form. On this type of soil, plants made normal growth up till August when the leaves began to turn yellow and were shed. The bolls were few and small containing some immature seeds. Generally the number of seeds per boll was also lower than normal. Application of sulphate of ammonia to such soil was found to remedy *tirak*. The relation between nitrogen deficiency and the 'bad opening' of bolls has already been discussed in Chapter III.

It was found that fields with such light sandy soils deficient in nitrogen contained patches which had high pH (8.5—8. 9) or small amounts of exchangeable sodium in the subsoil. In some cases the soluble salts though normal in quantities contained more of sodium salts than of calcium salts. Such patches of saline subsoil were found irregularly scattered about in light sandy fields. At one place a big or a small patch was found to contain sodium clay or abnormal amounts of soluble sodium salts in the subsoil while soil surrounding such a patch may have normal subsoil. Such intermingling of normal soil (light sandy) with soils with a high pH or with sodium clay in the subsoil or with abnormal amounts of sodium salts in the subsoil within a small area was of common occurrence. The detailed study of the crop, the analysis of the soil underneath, the effect of the application of ammonium sulphate on the plant growth, the chemical analysis of the leaves and the "tannin" reaction of the leaves, disclosed the nature of the soil conditions that were associated with *tirak* due to salinity in one case and due to nitrogen starvation in another case. Sulphate of ammonia was found to produce beneficial effect on the vegetative growth of the plants but was not found to have ameliorative effect on the opening of the bolls if light sandy lands were saline in the subsoil.

From what has been stated above it was necessary to distinguish *tirak* or 'bad opening' that occured on soils with saline subsoil from *tirak* caused by a deficiency on nitrogen. It is possible, by examining the crop in the fruiting stage, to know pretty exactly if the symptoms of *tirak* were caused by a deficiency of nitrogen in the soil or not. Application of "tannin" test was another rapid method of knowing the deficiency of nitrogen as explained in Chapter III. Similarly high concentrations of sodium salts in the subsoil could be known by the drooping leaves of the crop on such soils.

(*ii*) Hints For Collecting Soil Samples

It is necessary to point out that mere collection of soil samples and analysing them would not give any clue to the above established relationships between *tirak* and soil conditions. It was not enough to be told by a *zamindar* that *tirak* had occurred in such and such a field . On account of the great heterogeneity that existed in the soil it was absolutely necessary to make sure of the exact spots where *tirak* had occurred. It was necessary to take a number of bores even after the spot was located, as the salinity in the subsoil was so variable. Many a time, crops which were inadequately irrigated also showed shedding of leaves and 'badly opened' bolls. They should not be mistaken for *tirak* which occurred under saline conditions. Lack of cultivation may also produce 'badly opened' crop.

It was also noticed that light sandy soils deficient in nitrogen occurred at one end of a strip of land measuring 2 acres while soils with a very heavy and saline subsoil occurred at the other end. In one square of land (*i. e.* 25 acres) all types of soil conditions may be found. It was such intermingling in a small area of normal soil and soil where *tirak* developed that obscured the soil conditions associated with *tirak*. In a year of favourable season, the cotton crop in a field may show *tirak* only on patches which have a highly saline subsoil while the crop may be normal in the remaining parts of the field. Consequently *tirak* was not readily noticeable even though it was there. But *tirak* became noticeable when adverse weather conditions caused it to spread on the portions of the fields where a medium or low salinity existed in the subsoil. If the soil samples are taken in such a year, it is possible the analysis may only show low salinity in the subsoil and a conclusion may be drawn that there was nothing abnormal.

(*iii*) Methods used in soil analysis

Estimation of Exchangeable Calcium and other Cations in soils : Puri, A. N. (1936) Soil Science, *42* ; 47.

Estimation of Replaceable Na and K, etc., : Puri, A. N. (1935) Soil Science, *40* ; 249.

Estimation of Potassium : Milne, G. (1929) J. Agric. Sc. , *19* ; 541.

Mechanical analysis : Dispersion and stability of soil in water ; Puri, A. N. and others, Part II, Memoir Irri. Res. Inst., Lahore.

Determination of soluble Calcium : Standard oxlate method.

Determination of soluble sulphates: Barium sulphate method standard.

A New method of estimating Carbonates in soils: Puri, A. N. (1930) Agric. Res. Inst. Memoir.

CHAPTER V

GROWTH STUDIES ON *TIRAK*-AFFECTED CROP

The Punjab-American cotton plants showing the symptoms of *tirak* grew normally up to the reproductive stage when the leaves either began to turn pale green and yellow on light sandy soils deficient in nitrogen, or assumed drooping position on the soils which had high concentrations of soluble sodium salts in the subsoil. It was probable that the disordei in the metabolic processes of the plants on these two types of soils might be setting in at a much earlier date than the date of the appearance of these symptoms in leaves. It was assumed that the growth studies might reveal the time when such metabolic disorder actually occurred. The determination of the relative growth rate, the net assimilation rate, the percentage increase in dry matter and the percentage distribution of dry matter in different organs of the plants growing on such soils might indicate the stage at which the plants began to deviate from the normal course in their metabolism. Though the growth of the cotton plant has been studied before in different countries, such a study for the Punjab-American cotton was necessary on account of the development of *tirak* symptoms on two different types of soils. Such a study was, therefore, undertaken on the cotton plants grown on four different types of soils, *viz.*, (*a*) normal sandy loam, (*b*) sandy loam with saline subsoil, (*c*) light sandy soil with nitrogen deficiency and (*d*) light sandy soil with nitrogen deficiency and with saline subsoil. The relative growth rate was determined by the dry weight method employing the formula:

R.G.R. $=\text{Loge}\, W_2 - \text{Loge}\, W_1$ and the net assimilation rate by the formula

$$\text{N.A.R.} = \frac{(W_2 - W_1)\ (\text{Loge}\, L_2 - \text{Loge}\, L_1)}{L_2 - L_1}$$ where W_1 and W_2

represented the total dry weights of the plant at two successive stages of 14 days' interval, and L_1 and L_2 represented the dry weights of leaves per plant on the same dates. (Gregory, 1926).

(*i*) Growth Trends in Normal and *TIRAK*-Affected Plants

The detailed study of the growth trends for three years revealed that there were no major differences in thc growth trends of plants on the four soil types. There was a depression in the relative growth rate and in the net assimilation rate in the months of August and September on sandy loams with saline subsoil (Fig 8.) This depression might have arisen as a result of the plants suffering from a water deficit at that stage on account of the inability of the roots to absorb enough moisture to meet their requirements.

On light sandy soils the relative growth rate and the net assimilation rate were higher in the early stages of growth than in the normal sandy loams. These higher rates might be due to the vigorous growth made by the plants no light sandy soil which promoted extensive root development. But the limiting influence of the nitrogen factor became visible in the growth curves in September and October when relative growth and the net assimilation rates became lower than those of the plants on normal sandy loam (Fig. 8)

The maximum percentage increase in dry matter occurred generally by the middle of September on all types of soils except on sandy loams with saline subsoils

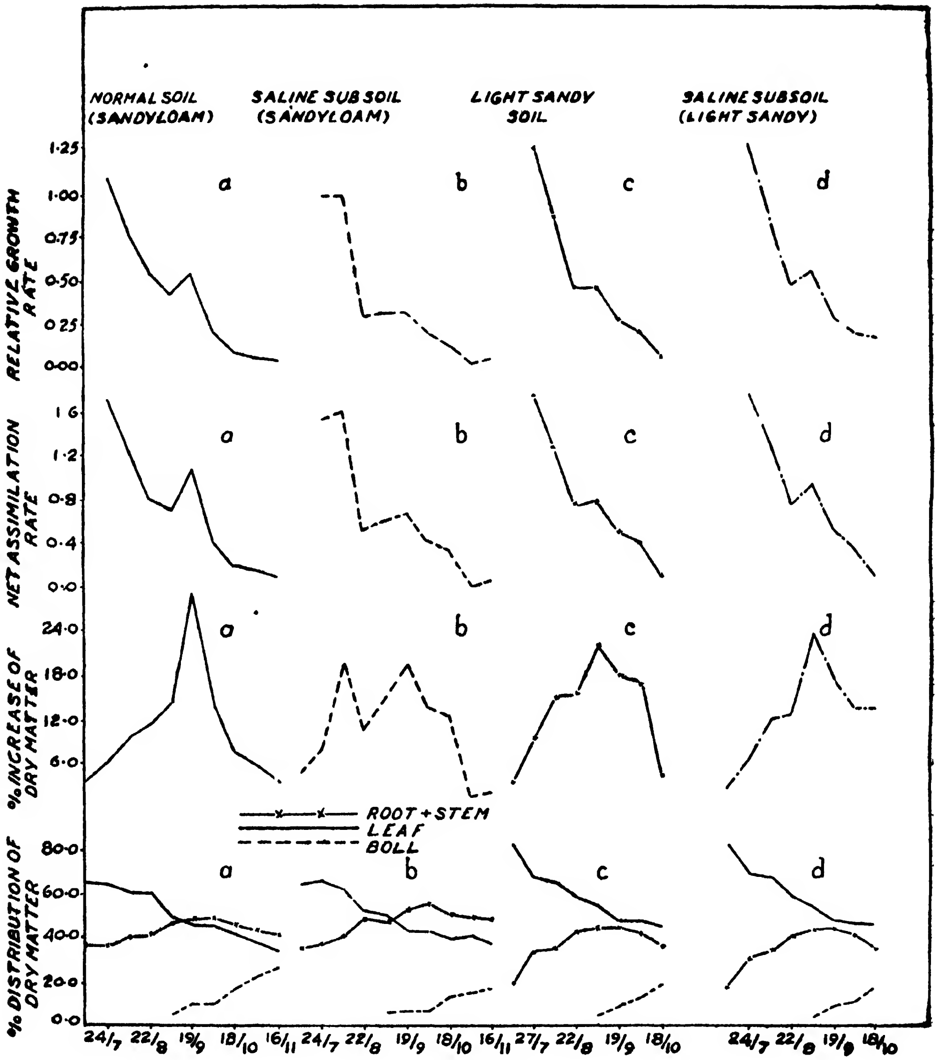

Fig 8 The relative growth rate, the net assimilation rate, the percentage increase in dry weight and the percentage distribution of dry matter in the different parts, of 4F Punjab-American Cotton plants on four different soil types; normal sandy loam, saline sandy loam, light sandy and saline sandy.

where no definite maximum was visible. The curve for the latter type of soil was very irregular as the crop suffered from a water deficit between two successive irrigations (Fig. 8).

When the percentage distributions of dry matter in the different organs of the plants on the four types of lands were studied it was found that the percentage of dry matter in the bolls was higher on normal sandy loam than on the other three

soils where *tirak* occurred. Another important difference was in the distribution of dry matter in the stems and leaves. On sandy loams the stems contained more percentage dry matter per plant than the leaves, while on light sandy soils there was more dry matter in the leaves than in the stems (Fig. 8).

(*ii*) GROWTH STUDIES OF THE BOLLS

The percentage dry matter of *tirak*-affected bolls as compared with the percentage dry matter in the bolls of normal plants indicated that the growth of bolls on *tirak*-affected plants did not proceed normally. A study of the growth of bolls at weekly intervals by the dry weight method on normal and two types of soils where *tirak* occurred was, therefore, considered necessary. A normal field, a sandy loam field with a saline subsoil and a field with light sandy soil were selected for this study. About 5000 flowers in each of the three fields were tagged in the last week of September when the peak in the flowering phase occurred. The weekly determinations of the dry weights of bolls from setting up to maturity were made. In the early stages of boll development 200 bolls were taken and this number was gradually reduced to 50 in the latter stages of development. The dry weights of carpels, lint and seeds were determined separately.

The growth of the bolls was found to cease 28 days after setting on the two types of soils where *tirak* occurred, while on normal soils the increase in the dry matter of the bolls continued up till 49 days (Fig. 9a). The dry weight of a *tirak*-affected boll was found to be nearly two-third the dry weight of a normal boll. Thus the growth of the boll of *tirak* affected plants generally ceased after the 4th week of its development, while the growth continued for seven weeks on normal soils (Fig. 9a.) *Tirak* condition was, therefore, preceded by the inhibition of the growth of bolls. If the dry weights of carpels and seeds were separately considered the same conclusions were arrived at (Fig. 9b and c.). The growth of the carpels and the seeds in *tirak*-affected plants ceased after the 4th week of development. The course of development of the lint was, however, different from that found in the case of the carpels and the seeds. The lint in *tirak*-affected boll continued to grow and to add to its dry matter even after the carpels and seeds had ceased to grow.The increase in the dry weight was small and was sufficient only to counteract a small fall in the dry wieght of the carpels that was noticeable in *tirak*-affected bolls after the 4th week . The dry weight of the lint of normal bolls was higher at all stages of development than dry weight of the lint in *tirak*-affected bolls (Fig. 9d).

When the weekly dry weights of bolls were calculated as percentages of the total dry weight it was found that the maximum percentage increase in the dry weight occurred during the second week of development (Fig. 10). *Tirak*-affected bolls later showed a rapid fall in the percentage increase in dry matter. This was expected as the growth was inhibited in *tirak*-affected bolls from the 5th week while it continued up to the 7th week in normal bolls.

The relative amounts of percentage dry matter in the different parts of a boll were different in the normal and *tirak*-affected bolls. The seeds contained the maximum percentage dry matter in normal bolls, while the carpels contained the maximum percentage dry matter in *tirak*-affected bolls.

Not only was the dry weight per boll higher in normal soils than the dry weight per boll in the other two soils types where *tirak* occurred, but the size of the boll was also bigger in the former than in the latter. The volume, the length and the diameter of the bolls from *tirak*-affected and the normal plants were determined at weekly intervals. It was found that the maximum volume of normal boll registered

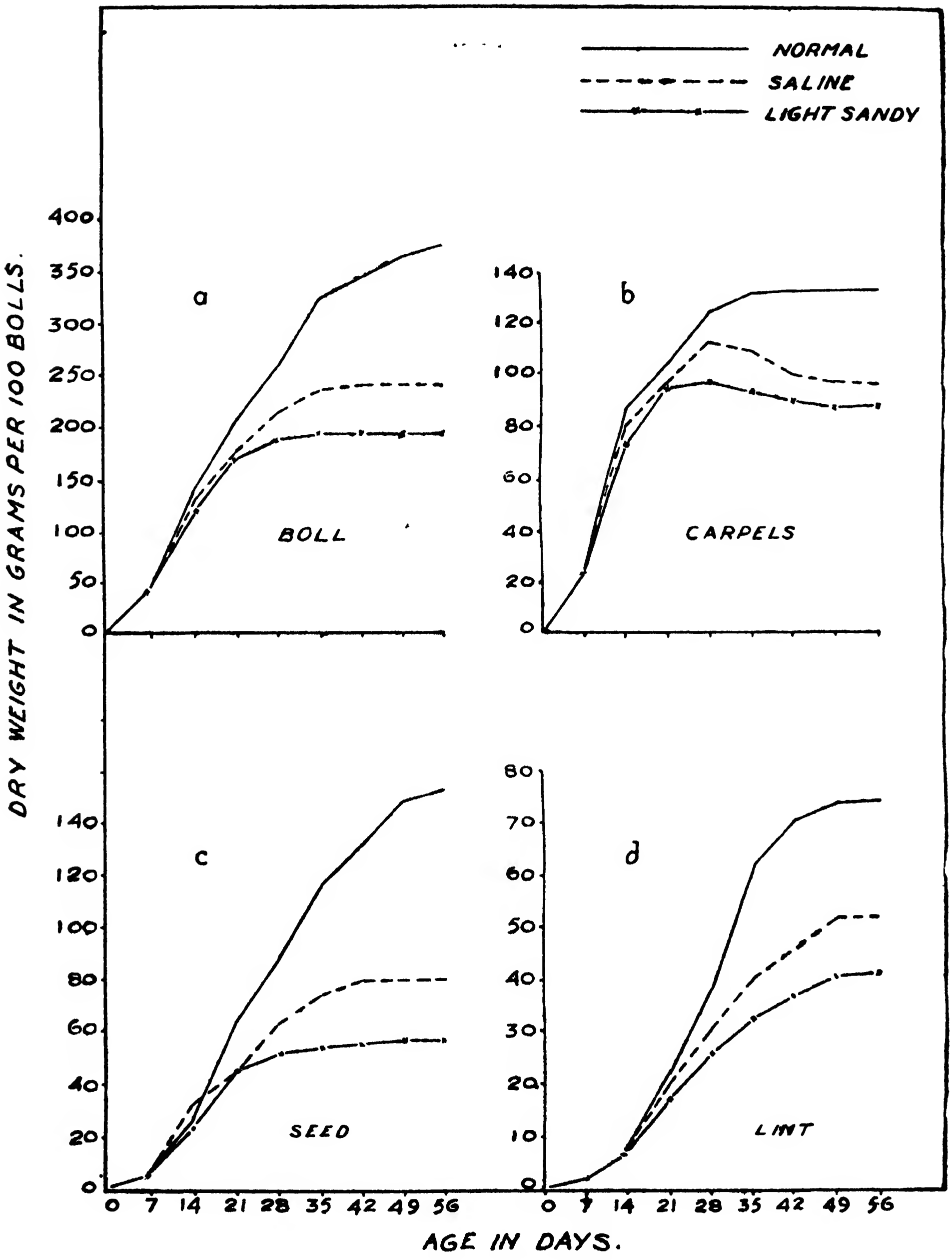

Fig. 9. The dry weights on the three soil types of (*a*) bolls, (*b*) carpels, (*c*) seeds and (*d*) lint per 100 bolls.

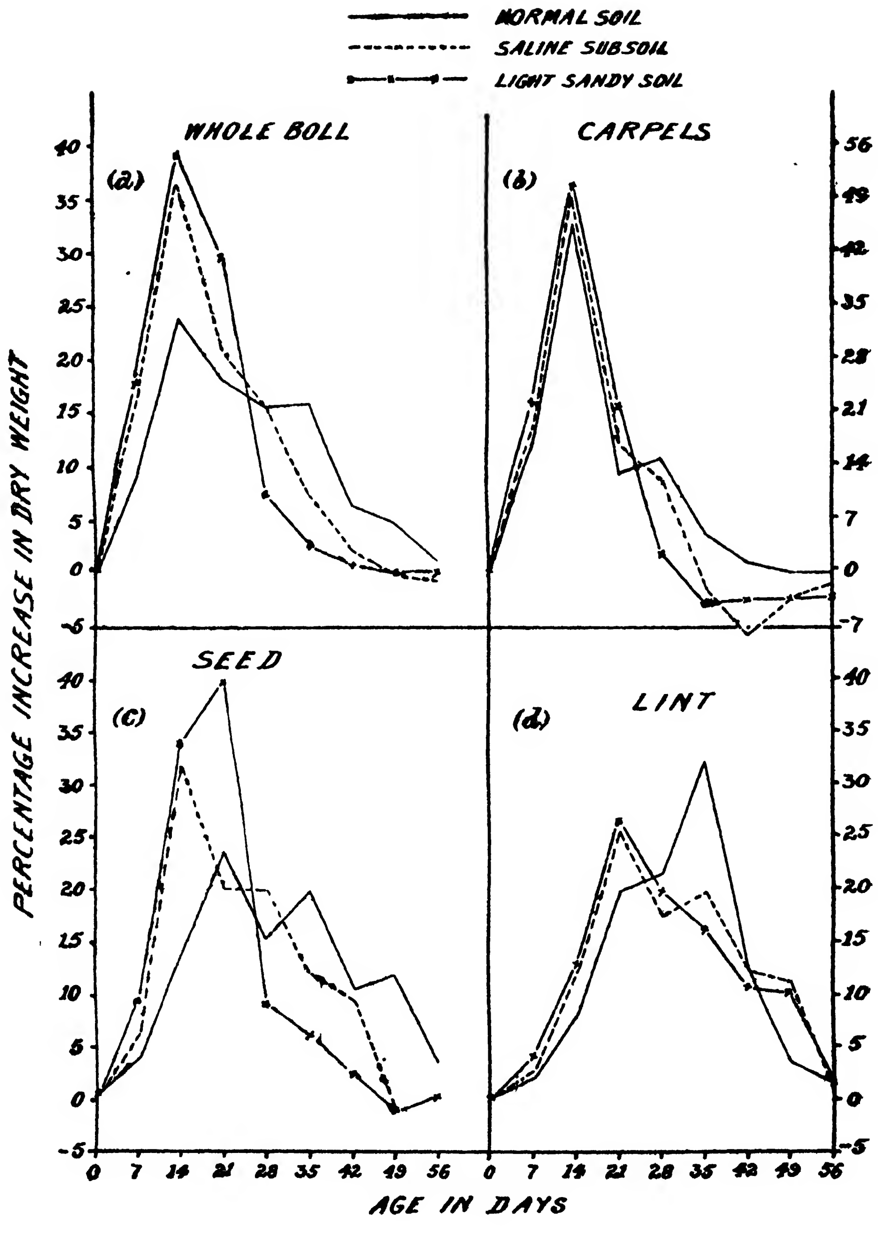

FIG. 10. The percentage increase in the dry matter, (*a*) boll, (*b*) carpels, (*c*) seeds and (*d*) lint per 100 bolls on the three soil types.

in the 5th week of development was 14.06 c.c. as compared with the maximum volume of 9 c.c. of the *tirak*-affected boll which was registered in the 4th week. 90% of the total volume of the boll was attained in the first three weeks, as this was the most active period of boll development. During the later stages of development there was a decrease in volume as the bolls began to lose moisture and become dry. (Dastur and Ahad, 1944.)

Though the volume and the dry weight of the bolls from normal plants were higher than those of the bolls from *tirak*-affected plants, the density, *i.e.*, the mass per unit volume was the same in all cases. In fact the density of *tirak*-affected bolls was slightly higher than the density of normal bolls. This may be due to the differences in the total volume of air (empty space) in the normal and *tirak*-affected bolls.

The bolls from normal plants were found to contain nearly 91% of the fully mature seeds while the bolls from *tirak*-affected plants contained only about 30% to 36% of fully mature seeds. The total number of seeds per boll varied from 30 to 35 on normal soils, while on saline sandy loams and light sandy soils the number of seeds per boll varied from 17 to 25.

It was clear that, on the two types of soils, where *tirak* occurred, the growth of the bolls ceased after four weeks and the weight and the size of the bolls were lower than those of the normal boll. The total number of seeds and the percentage of mature seeds were also relatively low in *tirak*-affected bolls.

The above mentioned facts regarding the differences in the boll development were again confirmed in another cotton season. For detailed results reference may be made to the paper published by Dastur and Ahad (1944).

The differences in the boll development on normal soils and on soils with saline subsoils applied to fields where *tirak* occurred in all seasons irrespective of weather conditions. These may be called permanent *tirak*-affected fields or patches under normal irrigations. *Tirak,* however, occurred on wider areas and in an extreme form during certain years. The climatic conditions which promoted the spread of *tirak* on extensive areas are discussed in another Chapter. In such years this 'disease' spread to soils which had low or medium salinity in the subsoil and where it did not appear under favourable conditions of weather. Examination of the bolls in such *tirak* years indicated that the bolls three to four weeks old were mostly affected as they apparently ceased growing. Once the growth stopped the bolls were not shed in the Punjab-American cottons as they did in *desi* cottons but they remained on the plant in that stage of development, and began to lose moisture and crack in the 5th or the 7th week after setting, with immature seeds and weak lint. It was very often noticed that all *tirak*-affected bolls were located on the topmost parts of the fruiting branches where they were exposed to direct sunlight, while the bolls which were situated on the lower nodes and which were protected by leaves, opened normally with all the seeds fully developed.

In the foregoing pages the trends in the growth of plants on different soil types were discussed but no reference had been made to the actual growth made by *tirak*-affected plants as compared with the growth made by normal plants. It was important to know the difference in the actual growth made by the plants on the different soil types.

(*iii*) Growth of Normal and *TIRAK*-Affected Plants

Light sandy soils were of two types. In one case the subsoil was normal and non-saline, while in the other case the subsoil either contained sodium clay or high concentration of soluble sodium salts. In the first type of soil, the application of sulphate of ammonia would remedy *tirak* and this has already been discussed in Chapter III, but the application of sulphate of ammonia on the second type of light sandy soils would not take effect on account of salinity in the subsoil (Chapter X). It was, therefore, necessary to determine the growth made by plants on the two types of light sandy soils.

Twenty plots of 1/56 acre each were selected in a field with light sandy soil where the subsoil was normal in one portion of the field and saline in the other. Ten plots had normal subsoil while the remaining 10 had saline subsoil. Out of 10 plots of each type 5 plots were manured with sulphate of ammonia at the rate of 50 lb. N. per acre.

A number of observations were regularly recorded on the crop. Height measurements of 10 plants and the dry weight determinations of stems, leaves and fruiting parts of 5 plants were made at fortnightly intervals in each one of the 20 plots. Similarly the number of bolls and the boll weight (*i.e.*, weight of seed cotton per boll) were recorded in each plot to assess the amount of *tirak*. The choice of plants was perfectly random. Yields of seed cotton per plot were also collected.

The data collected were subjected to statistical treatment by employing Fishers' method of analysis of variance to see if the differences in the morphological characters found in the plants on normal light sandy soil and on saline light sandy soil were significant or not. The main conclusions are summarised in Table XIV, which gives the analysis of variance and the main effects of treatments in relation to the different characters with appropriate standard errors.

Table XIV

Analysis of variance

Due to	D.F.	Height per plant in cm.		Dry weight per plant in gm.		No. of bolls per plant		Weight of seed cotton per boll in gm.		Yield of seed cotton in lb. per plot	
		Variance	F.	Variance	F.	Variance	F.	Variance	F.	Variance	F.
Soil	1	981.40	10.31**	27,676	7.68*	3.78	..	1.5401	46.81**	301.86	28.75**
Nitrogen ..	1	807.72	8.49*	14,905	..	635.06	29.45**	0.0616	..	358.70	34.16**
Soil × Nitrogen	1	57.46	..	4,867	..	2.38	..	0.114	..	102.60	9.77**
Error ..	16	95.15	..	3,602	..	21.56	..	0.0329	..	10.50	..

Main effects

	Height	Dry Weight	Boll No.	Boll Weight	Yield
Normal Subsoil	113.2	438.3	31.0	2.11	25.56
Saline Subsoil ..	99.2	363.9	31.9	1.56	17.79
Difference ..	14.0**	74.4*	—0.9	0.55**	7.77**
S. Ed. ..	±4.36	±26.8	±2.07	±0.081	±1.45

The results showed that the height per plant, the total dry weight per plant, the boll weight and the final yields were all significantly depressed on soils with saline subsoil, while there was no difference in the number of bolls produced per plant. Sulphate of ammonia had significantly increased the height, the number of bolls and the final yields, but its effect on the dry weight and boll size came out insignificant. The addition of nitrogen increased the boll number on light sandy soil with saline subsoil but it did not increase the boll weight, *i.e.*, did not ameliorate *tirak*.

As nitrogen had behaved differently on the two soils in the case of yields, the interaction of soil type with nitrogen was significant. There was a greater increase in yield on account of nitrogen application on normal light sandy soil than on light sandy soil with a saline subsoil.

Similar growth data were collected in a field with sandy loam soil where scattered patches of saline subsoil and normal subsoil were known to occur. Five patches of each subsoil type were selected. Along with 4F American, the *desi* cotton, Mollisoni 39 was grown in the same field and similar observations (except the dry weight) were recorded on this variety of cotton. As *desi* cottons did not show symptoms of *tirak* a study of their growth on saline subsoils was considered of interest.

The records of height, dry weight, number of flowers and bolls, the boll weight and the yield are given in Table XV along with main effects and standard errors. The main conclusions are stated below:—

TABLE XV

	Normal Subsoil		Saline Subsoil		Main effects			
	American 4F.	*Desi* Moll.	American 4F.	*Desi* Moll.	Soil.	Variety	Interaction	S. Ed.
Height per plant in cm.	115.2	160.2	83.4	110.0	41.0**	35.8**	9.2	±4.81
Dry weight per plant in gm.	595.9	..	304.8	..	..	..	..	..
Total number of flowers per 12 sq. feet	243.8	424.4	160.2	216.6	..	..	..	.
No. of bolls per 12 sq. feet	64.8	188.0	54.6	93.8	52.2**	81.2**	42.0**	±12.04
Weight of seed cotton per boll in gm.	2.13	1.40	1.58	1.37	0.29*	—0.47**	—0.26	±0.138
Yield per 12 sq. feet in gm.	139.4	267.8	87.2	129.2	95.4**	85.2**	43.2	±24.30

The heights and the dry weights were depressed on sandy loam with saline subsoil in the case of 4F American cotton. Similar depression in height was noticed in the case of *desi* (Mollisoni) cotton. The total number of flowers produced per unit area was less on saline subsoils than on normal soils. Salinity in the subsoil significantly decreased boll production, the boll weight and the yield in the American variety. In the *desi* variety there was similar decrease in boll production and yield but the boll weight was unaffected. As the reduction in the boll weight was caused by immaturity of seeds it was clear that the *desi* cotton did not suffer from *tirak* and maintained its normal boll weight. The significant decrease in yield in the case of the *desi* variety was solely due to a reduction in boll production but in

the case of 4F American cotton the decrease in yield was caused both by a reduction in the boll number and boll weight. It may again be pointed out that there was no reduction in the boll number per plant on light sandy soils with a saline or alkaline subsoil.

The suppression in growth on saline subsoils was caused by the injurious effects exercised on the root system by sodium salts in the subsoil. When the free soluble sodium salts were present in high concentrations the osmotic relations of the plants with the soil solution were also disturbed and a condition of physiological drought resulted. This temporary drought disappeared on irrigation when the surface non-saline layers became moist but it reappeared as the surface layers became dry. The experimental evidence that the free sodium salts produced the symptoms of *tirak* on soils with saline subsoil is given in the next Chapter.

CHAPTER VI

ARTIFICIAL REPRODUCTION OF *TIRAK*

If *tirak* symptoms in the Punjab-American cotton developed on account of the presence of sodium salts in the subsoil layers it was necessary to obtain experimental evidence to confirm that view. It would be also of interest to study the effect on growth of cotton plants, of the application of different sodium salts to normal non-saline soils as such a study on cotton had not been attempted before.

The study of the growth of 4F-American plants on saline subsoils had revealed that salinity or alkalinity in the subsoil did not alter the inherent growth characters of the plant. The trends in the relative growth rate and the net assimilation rate were found to be similar, on normal as well as on saline soils. The trends in the production of dry matter at each stage of growth were also similar except for small differences, in the case of sandy loams with saline subsoils. Salinity in the subsoil depressed the growth of all parts of a plant and the depressing effect was more pronounced on the sandy loams than on light sandy soils. It caused immaturity of seeds in American cottons (*G. hirsutum*). Thus the effect was quantitative and not qualitative except for a delay in the crop arrival on saline soils. Harris (1929) had also found similar delay in the crop arrival in Egyptian cotton in presence of high salinity. It was, therefore, undertaken to determine if similar quantitative effects on the growth of plants were reproduced by artificial applications of sodium salts to non-saline lands.

The problem of reproduction of *tirak* symptoms proved more complicated than it was at first imagined and early attempts proved entirely unsuccessful. There were various reasons for this lack of success. In the early stages of these attempts enough quantities of salts as they were found to exist under natural conditions, were not used. In order to make the subsoil saline trenches or pits were dug up to a depth of two or three feet. The salts were added in the pits or trenches and they were irrigated after the earth was replaced. The digging operation thus loosened the earth and increased aeration and, therefore, the growth of the roots was very vigorous in the upper two feet of the soil surface. The result was a very luxuriant plant growth.

The effects of injecting sodium salts into well grown plants in normal soils were also studied. Different concentrations of each sodium salt were used. The salt solution was injected from one of the branches on the main stem and the total

quantity of solution absorbed was recorded. As a result of a large number of injection experiments, it was found that the injections of sodium salts produced no effect on the opening of the bolls, though in some cases the plants when injected at the bolling stage were killed owing to salt injury and the bolls remained immature and cracked with immature seeds but this could not be regarded as reproduction of *tirak* as it occurred in nature.

The toxic effect of sodium chloride and sodium carbonate was tested out in 1937-38 in plots of 4F American cotton plants grown on normal soils. Sodium chloride at the rate of 1500 lb. per acre was added on the 9th October 1937. In another plot sodium carbonate was spread at the rate of 750 lb. per acre. The salts were applied at the base of each plant. The plots were then irrigated. The leaves showed signs of injury on the 8th day after application and they all drooped and died. The rootlets were found to be killed. The undeveloped bolls dried up but mature bolls (unopened at the time of application) opened normally. This was also the case of direct salt injury and could not be regarded as a reproduction of the 'disease.'

In the year 1938 an experiment was laid out where the salts were added below the surface. Under natural conditions, total concentrations of salts were low in the first two feet of the soil but they began to rise from the third foot downwards. Attempt was, therefore, made to reproduce similar rise in the concentrations of total salts from above downwards on a non-saline soil. Sodium chloride and sodium clarbonate were the two salts employed as these two have been known in case of other pants to be most toxic in their effect. The treatments were all combinations of $\left\{\begin{matrix}\text{o}\\ \text{sod. chl.}\end{matrix}\right\}$ $\left\{\begin{matrix}\text{o}\\ \text{sod. carb.}\end{matrix}\right\}$. The layout was randomised block arrangement with six replicates. Size of each plot was 15ft. × 10 ft. The quantities of each salt required, to raise the concentration of each, in each foot of the soil, as given below were calculated and used (Table XVI).

The earth up to a depth of 4 feet was removed in six-inch layers from each plot and heaped separately. The required quantity of each salt for the fifth foot was calculated and added after loosening the soil of the fifth foot. Soil of the last six inches of the 4th foot was replaced in the pit and the required quantity of each salt for that layer was weighed, added and thoroughly mixed with soil. The process was repeated up to the topmost layer. The plots were then irrigated. The crop was sown in May 1939.

TABLE XVI

Percentage concentrations of the sodium salts in different layers.

	Sod. carbonate	Sod. chloride.	Sod. chl. + Sod. carb.
1st foot	0.000	0.055	0.055
2nd ,, ...	0.025	0.110	0.135
3rd ,, ...	0.050	0.165	0.215
4th ,, ...	0.075	0.220	0.295
5th ,, ...	0.100	0.275	0.375

A number of observations were made in each plot during the growth of the crop. As the plants could not be sampled for dry weights on account of the small size of the plot, the weight of sticks and branches of plants was determined from each plot after harvesting. The number of bolls per plant, the weight of seed cotton per boll and the total yield from each plot were recorded.

The drooping of leaves was found to occur in majority of plots treated with sodium chloride and the mixture of sodium carbonate and sodium chloride.

The analysis of variance, the means and the significant interactions are given in Table XVII.

TABLE XVII

Analysis of variance and mean weight of stems, boll number, weight of seed cotton per boll and yield

Due to	D. F.	Stems		Boll Number		Weight of seed cotton per boll		Yield (Adjusted)	
		Mean square	F.	Mean square	F.	Mean square	F.	Mean square	F.
Blocks	5	826456	..	8844	..	0.0475	.	0.1376	..
Chloride .. .	1	6501045	9.80**	115926	5.44*	0.2072	..	0.5367	4.81*
Carbonate	1	6059145	9.13**	256267	12.02**	0.3876	8.16*	1.0309	9.23**
Interaction	1	1288530	..	33900	..	0.0376	..	0.6002	5.38*
Error	15	663238	..	21316	..	0.0475	..	0.1116	..

Due to	Wt. of stems in gm.	Boll Number per plot	Wt of seed cotton in gm. per boll	Yield in lb. (Adjusted)
Control	2781	505.9	0.995	1.11
Chloride	1740	366.9	0.809	0.81
Control	2763	539.8	1.029	1.19
Carbonate	1758	333.1	0.775	0.72
S. Ed.	±332.4	±59.6	±0.088	±0.147

Yield differential response ±0·208

Due to	Chloride		Carbonate	
	Presence	Absence	Presence	Absence
Chloride	..	..	+0.02	—0.62
Carbonate	—0.15	—0.79	..	..

The depressing effects of sodium salts on the dry weight of stems per plant, yields, boll number and boll weight were clearly visible and these effects were significant (Table XVII). The weight of seed cotton per boll was significantly reduced

under these treatments indicating that these salts had produced immaturity of seeds as they did under natural conditions. Sodium carbonate had proved more harmful than sodium chloride in reducing the boll weight and the boll number

The results of yield were statistically analysed after adjusting the yields for stand by the help of analysis of covariance (Fisher, 1936). The regression of yield on plant number, for plots treated alike, was found to be 0.0769 after eliminating differences due to block and treatments. The correlation between yield and plant number was 0.6609 and was significant.

The two treatments had also significantly depressed the yield. The interaction chloride into carbonate was significant and positive, indicating that carbonate had proved less harmfull in the presence of chloride than in its absence.

The experiment clearly indicated that the growth and yields were reduced by the presence of sodium salts. The opening of bolls was bad and the seeds had remained immature when the salts were added. Thus *tirak* symptoms were reproduced by additions of the sodium salts. In the above experiment the doses of salts added were rather heavy and they had proved very toxic and the plants were very stunted in size.

(i) STUDY OF THE EFECT OF SODIUM SALTS ON THE GROWTH OF 4F PLANTS.

Another experiment to study the effect of sodium salts on the growth and development of *tirak* was, therefore, laid out in the cotton season of 1939-40, using smaller concentrations than those used in the above-mentioned experiment. The concentrations of salts used were such that when distributed over a depth of four feet they would be nearly the same as those generally found in patches where *tirak* occurred. These patches generally contained chlorides, bicarbonates and sulphates, while sodium carbonate was not present in all cases. Sodium sulphate was not included as previous experience had shown that it was not having any effect on the plant in concentrations in which it occurred in such soils. The experiment therefore, was designed to study the effects of sodium carbonate and sodium bicarbonate (quality) at three levels (o, single dose, double dose), in combination with three levels (o, single dose, double dose) of sodium chloride. The combination carbonate and bicarbonate was automatically excluded. There were thus 18 treatments comprising all combinations of the following :

Quality	Quantity	Chloride
	o	o
sod. bicarbonate	single dose	sod. chloride I
sod. carbonate	double dose ..	sod. chloride II

All treatments were completely randomised in each block. Three replicates were provided. Plot size was 1/81 acre.

The quantity of each salt to be added to the soil was calculated so as to give the required concentration for one acre-foot of soil. The percentage concentration of a single dose of chloride was kept equal to the percentage concentration of a double dose of carbonate or bicarbonate. The actual quantity of each salt in each dose and its percentage concentration in one acre-foot of soil are given below in Table XVIII.

TABLE XVIII

	Actual quantity added in lb. p. a.	% concentration of the salt per acre foot of soil	% concentration of the acid radical p. a.
Sodium chloride (single)	8000	0.182	0.109
,, ,, (double)	16000	0.362	0.218
Sodium bicarbonate (single) ..	3336	0.076	0.054
,, ,, (double) ..	6672	0.151	0.109
Sodium carbonate (single)	4288	0.097	0.054
,, ,, (double).. ..	8576	0.195	0.109

For calculating the percentage concentrations for one acre-foot of the soil it was taken that a cubic foot of soil weighed 100 lb. and consequently an acre-foot would weigh 4.4 million pounds. These quantities of salts when added to the soil were expected to be washed down by irrigation at least to a depth of four feet. The soil of the field where this experiment was laid out was normal (without salinity). Salts were added behind a deep furrow-turning plough on 16th-18th March and the plots were irrigated three times at regular intervals before sowing cotton seeds so that the salts might be washed down to lower layers and should not injure the seedlings. 4F American cotton was sown by the middle of May. As it was undertaken to study the effect of sodium salts on the growth of plants and on the development of *tirak* the following data were recorded. The total dry weight per plant and the dry weights of its different organs; stems, leaves and flowers plus bolls were determined on the 18th November. A 5-plant sample was taken from each plot. The height and node numbers of the main axis were determined from 5 plants in each plot at 10-day interval. The rate of flowering (5 plants from each plot) was also recorded during the flowering phase. The number of bolls per plant and the weight of seed cotton per boll were determined in two separate samples of five plants each. The final yield of *kapas* for each plot was also determined. For detailed results reference to the published paper by Dastur and Sucha Singh (1942) may be made.

Sodium chloride in low concentrations depressed to a small extent the vegetative growth but had no effect on the fruiting parts and yields (Tables XIX and XX). The same salt under high concentrations was found to exercise a very great depressing effect on its vegetative and fruiting parts. The total dry weight per plant, height per plant, leaf area, yields and boll weight were significantly lowered in the presence of sodium chloride when applied at the rate of 16000 lb. per acre. The weight of seed cotton per boll was greatly reduced indicating immaturity of seeds and consequently the chief symptom of *tirak* was reproduced in the presence of sodium chloride (Table XX).

Sodium carbonate in low concentrations (4288 lb. per acre) showed some depressing effect on the vegetative growth but it was found to have a small stimulating

effect on production of the boll material and consequently the yields. The most noticeable feature was the increase in the boll weight. High concentrations of the same salt (8576 lb. per acre) depressed greatly the vegetative growth resulting in low dry weights and heights. The yields were lowered as compared with the yields obtained under low concentrations of this salt. It may also be stated that the toxic effects of these sodium salts would depend on the clay content of the soil where an experiment is laid out. These salts have been found to prove more toxic on light sandy soils than on sandy loams which contained less proportion of sand fraction.

Both the salts had decreased the internodal lengths but had no effect on the number of nodes. The decrease in the internodal length indicated a deficiency of water as cotton plants were found to produce smaller internodes in the absence of heavy waterings (Crowther, 1934).

Sodium bicarbonate had no effect on the growth of the plant either under low or high concentrations except for an indication of a stimulating effect on yields.

The effects on the plant development of sodium carbonate and of sodium bicarbonate were different in the presence of sodium chloride. The depressing effect of carbonates on plant's growth increased in the presence of sodium chloride so much so that the dry weights, heights, boll material and yields were greatly reduced under high concentrations of the two salts (Tables Nos. XIX & XX). The case was different with sodium bicarbonate where this salt in high concentration appeared to decrease the depressing effects of high concentration of sodium chloride. It was on account of this differential behaviour of the two salts in the presence of chloride, that the interaction quality with chloride was found to be significant on dry weight, height and boll material (Tables XIX & XX).

Thus sodium chloride depressed both the vegetative growth and the yields. It also produced immaturity of seeds and thus caused bad opening. Carbonate decreased the vegetative growth but had a stimulating effect on fruiting parts in low concentrations. Bicarbonate in high concentrations appeared to decrease the depressing effect on yields of high concentration of sodium chloride.

It had already been shown in Chapter IV that free sodium salts were present in abnormal quantities in Punjab soils where *tirak* occurred. The sodium salts found in such soils were chloride, bicarbonate and sulphate of sodium while sodium carbonate was either present in very small amounts or was absent. The presence of these salts disturbed the osmotic relations of the plant with the soil and seriously interfered with the absorption of water resulting in a condition of physiological drought. These salts might also affect the growth of the roots. It appeared from the results discussed above that the disturbance in the presence of sodium chloride was greater than in the presence of sodium bicarbonate, as in the experiments, no depressing effect on plant's growth was visible when the latter salt was applied in concentration in which it was generally found to be present in such saline soils. It was quite possible that in much higher concentrations than those used here, any of the sodium salts may also produce similar depressing effects on growth. When sodium carbonate was present along with other salts the depressing effect was greatly aggravated. Thus the intensity of *tirak* symptoms would depend on the total concentrations of these salts, their nature and their relative proportions in the soil. It was the combined effect of these salts that produced *tirak* symptoms in natural conditions and it might be modified by other soil conditions like the clay content and soluble calcium salts.

The investigation reported here had thus yielded a direct experimental evidence that free sodium salts in the subsoil were causing *tirak* in the Punjab-American cottons.

Table XIX

Effect of sodium salts on total dry weight, dry matter of bolls and height.

	Total dry matter in gm. per plant						Dry matter of bolls in gm. per plant						Height in cm. per plant					
	Con-trol	Sod. Bic. I	Sod. Bic. II	Sod. Carb. I	Sod. Carb. II	*Mean*	Con-trol.	Sod. Bic. I	Sod. Bic. II	Sod. Carb. I	Sod. Carb. II	*Mean*	Con-trol	Sod. Bic I	Sod. Bic. II	Sod. Carb. I	Sod. Carb. II	*Mean*
Control	352	337	332	346	303	337	73	76	77	82	88	78	93 2	91.2	92.7	90.1	86.6	91.1
Sod. Chl. I	317	341	256	248	282	294	73	79	65	84	66	73	85.9	88.2	82.3	76.2	80.7	83.2
Sod. Chl. II	243	278	302	189	153	234	61	77	81	61	51	65	76.8	77.7	81.1	65.0	55.6	72.2
Mean	*304*	*319*	*296*	*261*	*246*	*288*	*69*	*77*	*74*	*76*	*68*	*72*	*85.3*	*85.7*	*85.4*	*77.1*	*74.3*	*82.1*

Mean dry matter per plant in gm.

Sod. Chl.	Chl. O	Chl. I	Chl. II
	337.1	293.8	234.6
Quality	Sod. Bic.		Sod. Carb.
	307.7		253.8
Quantity	O	I	II
	304.1	290.1	271.4

S. Ed. = ±20.5

Mean boll matter in gm.

Sod. Chl.	Chl. O	Chl. I	Chl. II
	78.3	73.6	65.3
Quality	Sod. Bic.		Sod. Carb.
	76.0		72.0
Quantity	O	I	II
	69.2	76.4	71.6

S. Ed. = ±6.190

Mean height per plant

Sod. Chl.	Chl. O	Chl. I	Chl. II
	91.14	83.17	72.17
Quality	Sod. Bic.		Sod. Carb.
	85.52		75.69
Quantity	O	I	II
	85.27	81.38	79.82

S. Ed. = ±2.63

Interactions

	O	Sod. Chl. I	Sod. Chl. II
Sod. Carb. ..	325.0	265.3	171.1
Sod. Bic. ..	334.6	298.6	289.8
Difference ..	—9.6	—33.3	—118.7

S. Ed. = ±35.49

Interactions

	O	Sod. Chl. I	Sod. Chl. II
Sod. Carb. ..	85 0	75.1	56.0
Sod. Bic. ..	76.5	72.3	79 1
Difference ..	+8.5	+2.8	—23.1

S. Ed. = ±10.72

Interactions

	O	Sod. Chl. I	Chl. II
Sod. Carb. ..	88.33	78.43	60.30
Sod. Bic. ..	91.93	85.23	79.41
Difference ..	—3.60	—6.80	—19.11

S. Ed. = ±4.566

Table XX

Effect of sodium salts on boll number, boll weight and yield.

	Total number of bolls per plant						Weight of seed cotton in gm per boll						Final yields in gm. per plot (1/186 acre)					
	Control	Sod. Bic. I	Sod. Bic. II	Sod. Carb. I	Sod. Carb. II	Mean	Control.	Sod. Bic. I	Sod. Bic II	Sod. Carb. I	Sod. Carb. II	Mean	Control	Sod. Bic. I	Sod. Bic. II	Sod. Carb. I	Sod. Carb. II	Mean
Control	34.1	44.4	38.1	37.6	37.6	37.6	1.22	0.99	0.99	1.25	1.32	1.16	2248	2188	2133	2472	2493	2297
Sod. Chl. I	38.2	42.2	42.8	50.3	38.5	41.7	1.02	1.15	1 32	1.35	0 79	1.10	2107	2297	2911	2830	1576	2305
Sod. Chl. II	34.2	34.1	36.0	32.7	32.4	33.9	0.83	0 81	0.96	1.15	1.10	0.95	1576	1551	1866	1900	1639	1685
Mean	35.5	40.2	38.9	40.2	36.2	37.7	1.02	0.98	1.09	1.25	1.07	1 07	1977	2012	2303	2401	1903	2095

Mean Boll number.

Sod. Chl. ..	Chl. O	Chl. I	Chl. II
	37.6	41.7	33.9
Quality ..	Sod. Bic.		Sod. Carb.
	39.5		38.2
Quantity ..	O	I	II
	35.5	40.2	37.5

S. Ed. = ± 2.42

Mean weight of seed cotton per boll.

Sod. Chl. ..	Chl. O	Chl. I	Chl. II
	1.16	1.10	0.95
Quality	Sod. Bic.		Sod. Carb.
	1 04		1.16
Quantity.. ..	O	I	II
	1.02	1.12	1 08

S. Ed. = ± 0 0937

Mean yield per plot in gm.

Sod. Chl. ..	Chl. O	Chl. I	Chl. II
	2297	2305	1685
Quality	Sod. Bic.		Sod. Carb.
	2157		2151
Quantity. ..	O	I	II
	1976	2206	2103

S. Ed. = ± 184.5

CHAPTER VII

PHYSIOLOGICAL CHEMISTRY OF *TIRAK*-AFFECTED 4F PLANTS

It was already demonstrated in Chapter III that the yellowing and premature shedding of leaves in the Punjab-American cottons on light sandy soils were symptoms of nitrogen starvation and the applications of nitrogen prevented the development of these symptoms on such soils When nitrogen was applied to such soils the nitrogen level in the leaves was found to increase and the premature yellowing and shedding of leaves did not occur. The drooping of leaves was a feature of *tirak*-affected plants on soils with a saline subsoil where also 'bad opening' of the bolls occurred. The common symptom of *tirak* on both the soil types was, therefore, immaturity of seeds and a study of the physiological chemistry of *tirak*-affected plants on the two types of soils was necessary to determine the nature of physiological disturbance which led to the production of partially or wholly immature seeds.

It was mentioned in Chapter III that the immaturity of seeds was lessened by the applications of nitrogen to light sandy soils. It was, however, found that similar applications to soils which had free soluble salts or sodium clay in the subsoil did not prove effective in lessening the seed immaturity. Thus the problem appeared complicated.

The immaturity of seeds was known to occur in other crops where one of the essential elements like potash or phosphorus was deficient but the direct applications of potash or phosphorus were not found to increase the maturity of seeds in the Punjab-American cottons.

In order to determine the chemical basis of *tirak* it was first necessary to study the mineral composition and the uptake of minerals by the American cotton plants grown on normal soils with a view to extend these observations on the two soil types where *tirak* occurred.

(*i*) MINERAL COMPOSITION OF NORMAL 4F PLANTS

The mineral composition of the cotton plant at one stage or the other had been determined by workers abroad (Hutchinson and Patterson, 1892; Fraps, 1919; McHargue, 1926). White (1914,1915) found that maximum amounts of nitrogen potash and phosphorus were absorbed by the cotton plant at the flowering stage. Similar findings have also been reported by Kudrin (1929), Holley, Pickett and Dulin (1931), Armstrong and Albert (1931) and Murphy (1936).

The mineral composition of the 4F American plants at maturity in the Punjab on normal soil under usual spacing of $3' \times 1\frac{1}{2}'$ are given below (Table XXI). The results have been expressed in grams per plant and per 100 grams of the whole plant. The methods of analysis used are given in the Appendix at the end of the Chapter. The crop was sown on 8th May, 1935. The results showed that the cotton plant contained large amounts of lime, potash, nitrogen and sulphates while the other minerals were found in smaller quantities.

The number of cotton plants with the spacing adopted was roughly 9,000 per acre. The quantity of each mineral absorbed by an acre of American crop sown early in May could thus be calculated and is given below (Table XXII).

Table XXI

Mineral composition of 4F Amerian plants

(On 24th December, 1935)

Dry wt.	Silica free ash	Nitrogen	Potash	Lime	Magnesia	Aluminium + iron	Phosphoric acid	Sulphates	Chlorides
				(gm. per	plant.)				
864.7	69.47	14.52	17.84	19.37	3.79	0.49	3.02	12.95	2.73
			(gm. per	100 gm.	of the	whole pl	ant.)		
100	8.04	1.68	2.07	2.24	0.44	0.06	0.35	1.50	0.32

Table XXII

Quantities of minerals in lb. absorbed by an acre of cotton crop

Nitrogen	Potash	Lime	Magnesia	Aluminium + iron	Phosphoric acid	Sulphates	Chlorides
288	353	384	75	10	60	256	54
	(Qua	ntities of	minerals in	lb. lost fro	m the soil	per acre.)	
177	190	90	42	3	40	66	32

Out of the total quantity absorbed a portion of it was returned to the soil by the roots and the shed leaves which remained in the soil and therefore the actual loss of these minerals from the soil was greatly reduced as the leaves contained the largest concentrations of these substances. Thus there was in a field of average fertility a loss of 190 lb. of potash, 177 lb. of nitrogen, 90 lb. of lime, 66 lb. of sulphur and 40 lb. of phosphoric acid every time an acre of cotton crop was grown in a field.

The leaves were found to contain maximum concentrations of lime, sulphate and potash when the crop matured.

The mineral compositions of the roots, stems, leaves and flowers and bolls were determined at fortnightly intervals to obtain an idea of the uptake of different minerals at different stages of growth. The percentage increase of each mineral for each stage in the whole plant was determined and it was found that the maximum increase in the uptake of each mineral occurred by the middle of September (Fig. 11). This was the stage when the maximum percentage increase in the dry matter of the plant also occurred as already shown (Fig. 8). Thus this was the period of maximum activity.

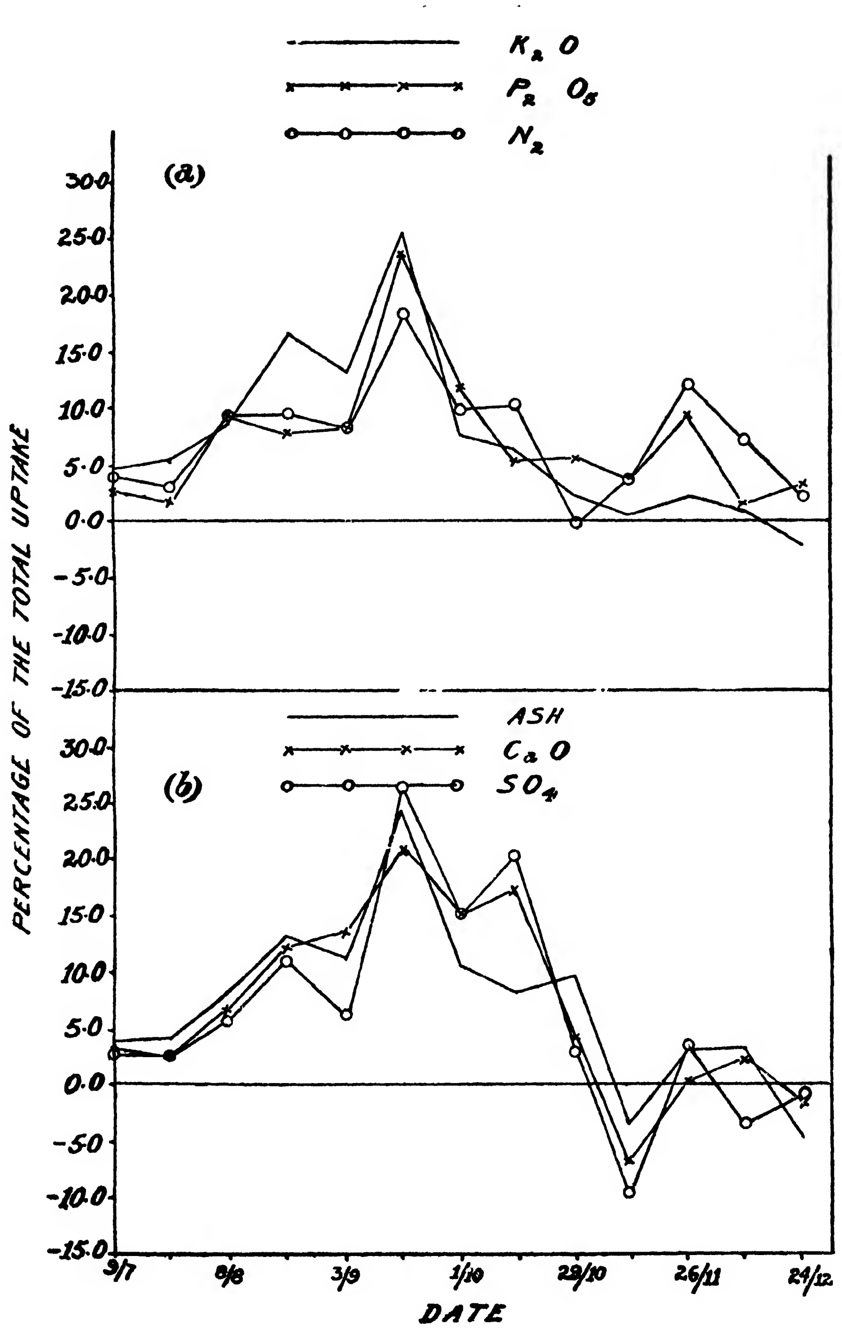

FIG. 11. The percentage of the total uptake of (a) potash, nitrogen, phosphoric acid and (b) total ash, sulphates and lime at different stages of growth.

(*ii*) The Uptake and Distribution of Minerals in Normal 4F Plants

A study of the concentration of each mineral at each stage of growth in the different parts of the plant revealed that the concentration of nitrogen and phosphorus decreased in the leaves as the bolls matured while they remained almost constant in the stems and roots (Fig.12). In the case of potash a decline in the concentration occurred in the roots and stems along with the leaves when fruits developed. Thus the first two elements travelled from the leaves to the bolls, while potash travelled from all the vegetative organs to the fruiting parts. The concentrations of lime and sulphates in the leaves remained unchanged throughout the whole period indicating that there was a continuous absorption of these minerals from the soil and the requirements of the bolls were either met directly or *via* the leaves from the soil (Figs. 12 & 13). There was also a small decrease in the concentration of magnesia in the leaves up till October after which it remained unchanged (Fig.13). There was an increase in the concentration of iron in all the vegetative parts in the early stages of growth after which there was a fall in the leaves but not in the stem and roots (Fig13). The concentrations of chlorides declined in the early stages of development in all parts of the plant (Fig. 13). Thus most of the minerals except lime and sulphates got depleted from the leaves at the fruiting stage.

A study of the percentage distribution of each of these minerals in the different organs of the plant at different stages of growth supported the above conclusion that the leaves got depleted of most of their ash constituents and nitrogen when the bolls began to develop. Nitrogen, phosphorus (Fig. 14), magnesia, chlorides and iron (Fig.15) decreased in leaves while potash decreased in all the vegetative parts (Fig.14). The percentage distribution of lime and sulphates in leaves remained constant at all stages of growth (Figs. 14 & 15). For further detailed information on the mineral uptake of cotton plant in the Punjab a reference to the published paper by Dastur and Ahad (1941) may be made.

(*iii*) The Uptake and Distribution of Minerals in *Tirak*-Affected 4F Plants

In order to study the mineral uptake in *tirak*-affected crop, a field with a light sandy soil where *tirak* due to a deficiency of nitrogen was known to occur was selected. A field where normal crop was known to grow was also selected, as the differences in the mineral uptake of normal and *tirak*-affected plants, if there be any, could only be detected by comparison. 5-plant samples at random were taken for analysis at monthly intervals. The roots, stems, leaves and fruiting parts (buds, flowers and bolls) were separately analysed for nitrogen, phosphoric acid potash and lime. No differences between the mineral contents of the roots and stems of normal and *tirak*-affected plants were noticed while marked differences in leaves can be seen from Fig.16A. The leaves of *tirak*-affected plants were found to be deficient in nitrogen, phosphoric acid and lime from the early stages of growth while potash was found to be deficient from mid-August, *i.e.*, at the pre-flowering phase.

Similar investigations of *tirak*-affected plants on soils with saline subsoil revealed that nitrogen and lime were deficient in leaves from the early stages while potash became low at the flowering phase (Fig. 16B). Thus *tirak*-affected plants on both the soil types showed a low nitrogen, and lime in the leaves (Dastur and Ahad, 1945).

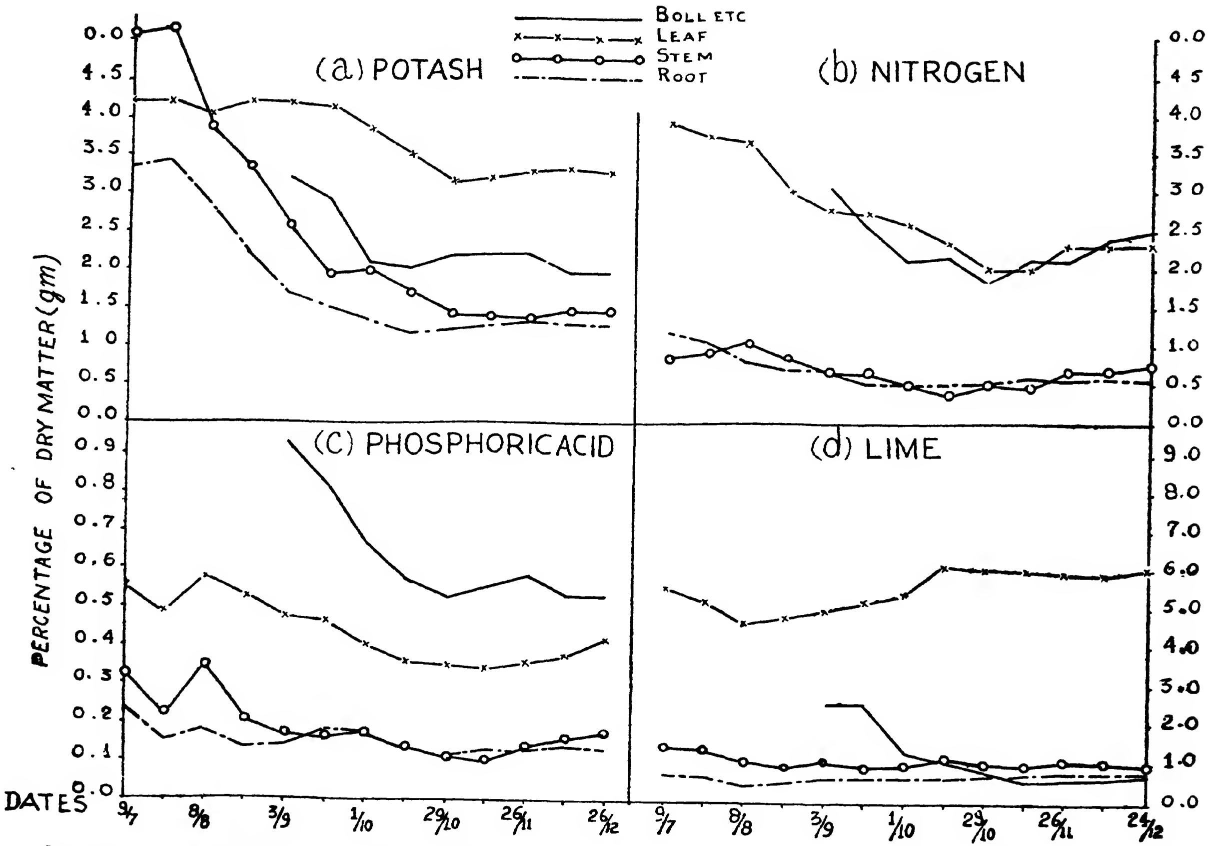

FIG. 12. The percentage of potash, nitrogen, phosphoric acid and lime in the roots, stems, leaves and flowers and bolls of 4F Punjab-American Cotton at different stages of growth on normal sandy loam.

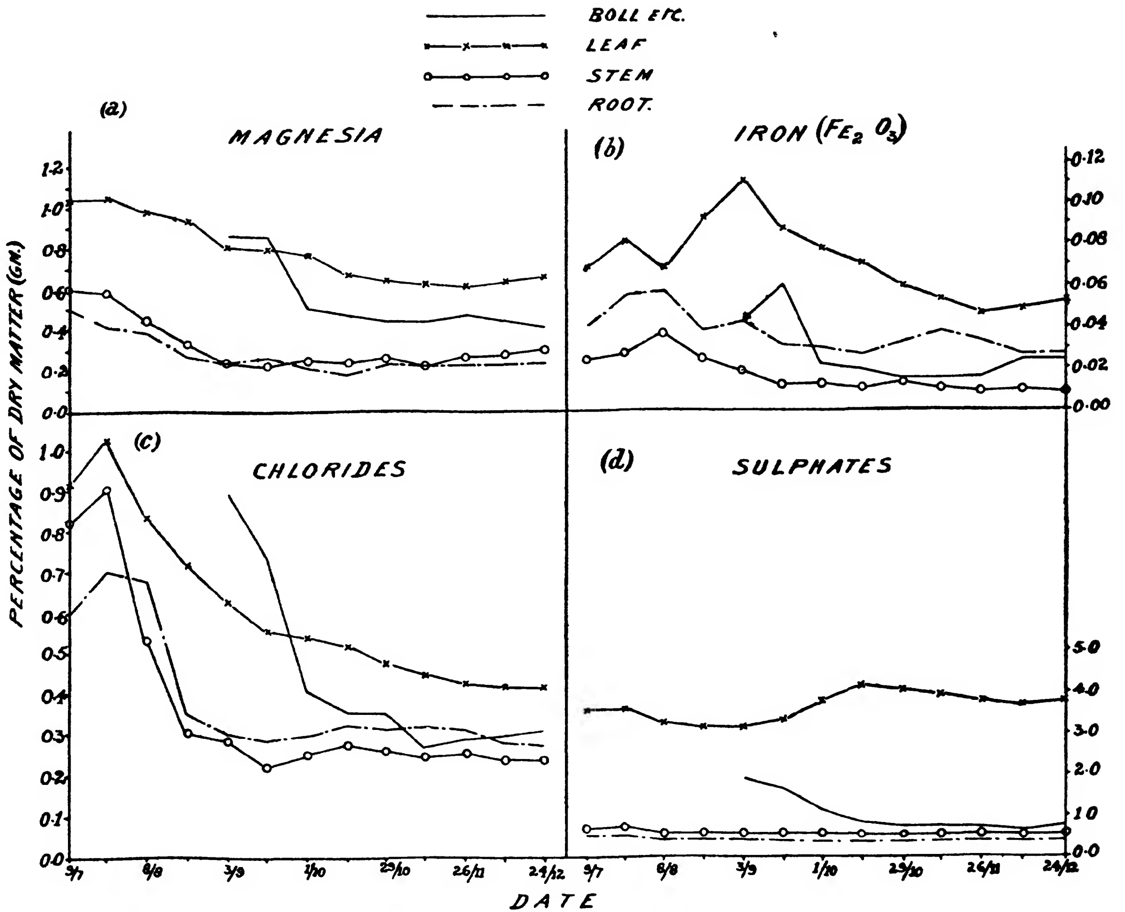

FIG. 13. The percentage of sulphate, magnesia, iron and chlorides in the roots stems, leaves and flowers and bolls of 4F Punjab-American Cotton at different stages of growth on normal sandy loam.

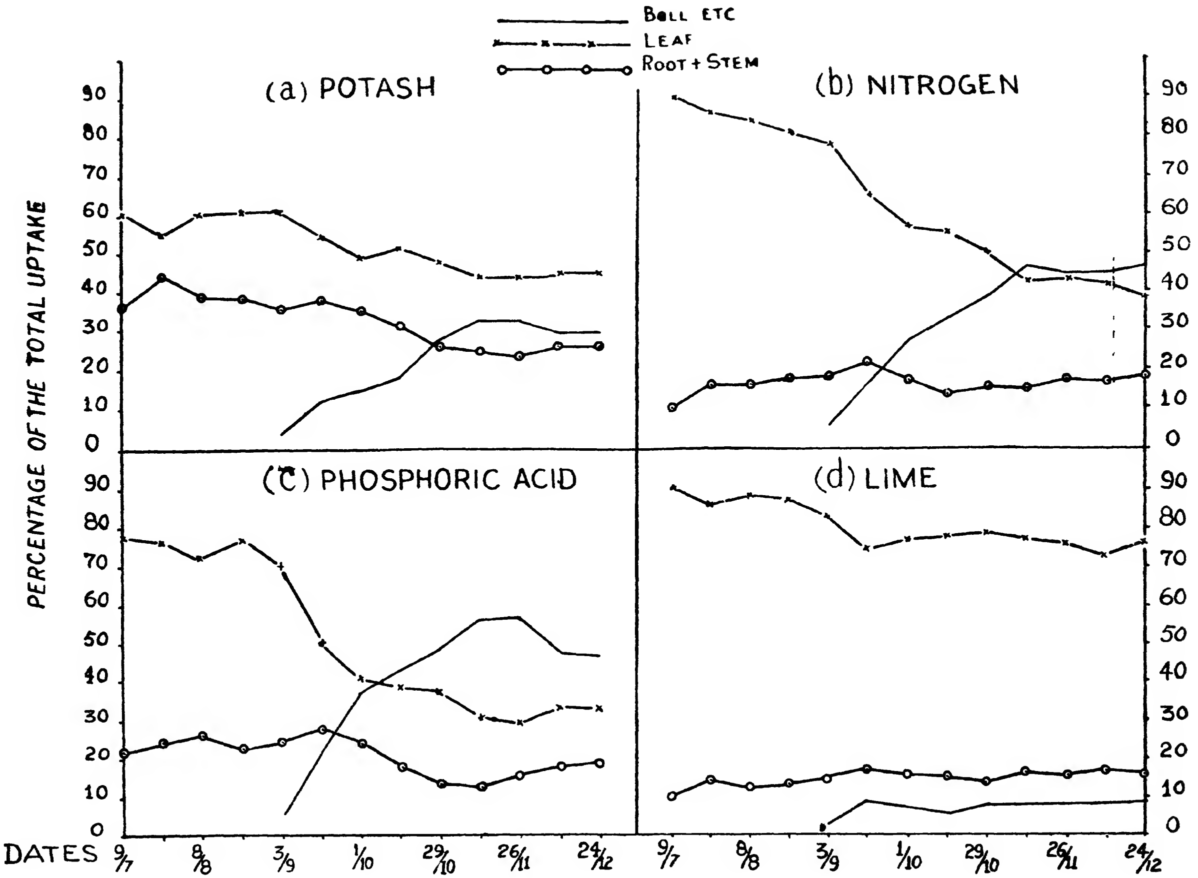

FIG. 14. Percentage distribution of potash, nitrogen, phosphoric acid and lime in different parts of 4F Punjab-American cotton at different stages of growth on normal sandy loam.

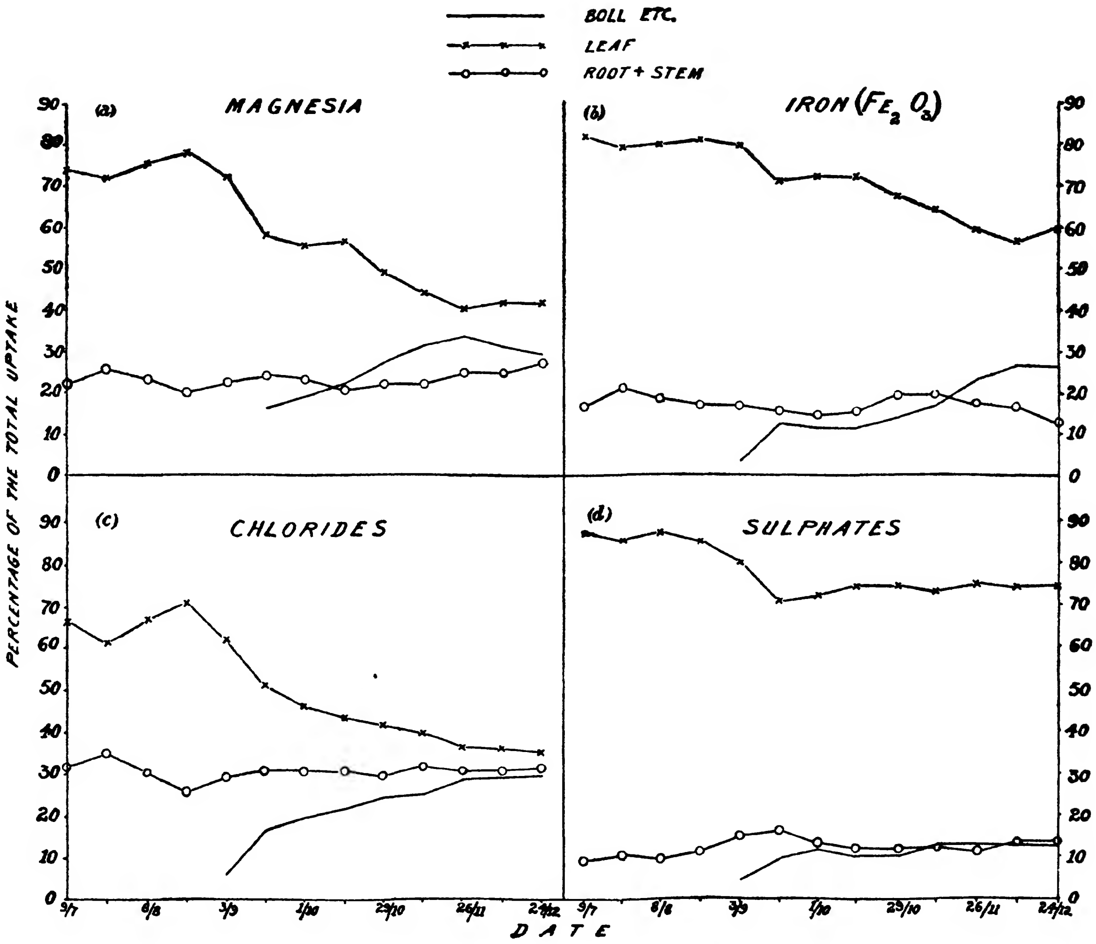

Fig. 15. Percentage distribution of sulphates, magenesia, iron and chlorides in different parts of 4F Punjab-American Cotton at different stages of growth on norma .sandy loam.

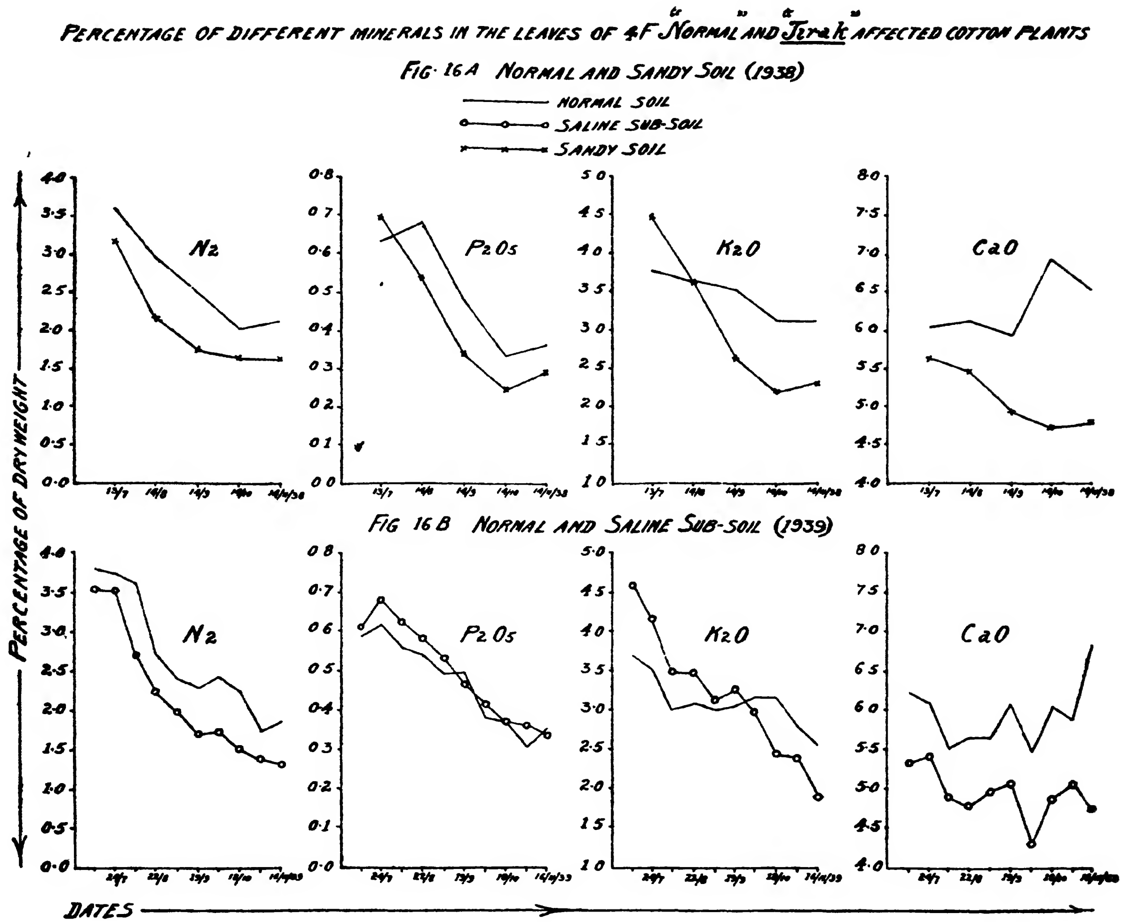

FIG. 16. Percentage of nitrogen, phosphoric acid, potash and lime in the leaves of normal and *tirak*-affected plants at different stages of growth on (*A*) light sandy soil and (*B*) soil with saline subsoil.

(*iv*) Mineral Composition of Bolls at Different Stages of Development

The above-quoted results indicated some disturbance in the uptake of minerals in the two soil types where *tirak* occurred. If immaturity of seeds was a direct or an indirect effect of deficiency of any one of the important minerals, it should also be possible to detect it in the developing bolls. A study of the metabolism of developing bolls was, therefore, considered necessary. A normal field, a field where *tirak* occurred on account of salinity in the subsoil and a field where *tirak* occurred on account of a deficieny of nitrogen were selected and 5000 flowers were tagged in each field on the same day in the month of September. Weekly samples of developing bolls, after they were set, were taken from each field for analysis up to the time the bolls opened. In the early stages a larger number of bolls was collected for analysis but the number was reduced to 50 when the bolls began to mature. The carpels, seeds and lint were separately analysed each week for nitrogen, potash, phosphoric acid and lime.

A study of the concentrations of the four minerals in the carpels, seeds and lint of normal and *tirak*-affected bolls at different stages of development revealed the following trends:—

The concentrations of nitrogen, phosphoric acid and up to a certain stage only of lime, decreased (Figs. 17A, 17 B, 18A & 18B) while the concentration of potash increased in the carpels as the bolls matured. The potash content of the carpels of *tirak*-affected bolls remained constant in the final stages of growth.

The concentrations of nitrogen, phosphoric acid and lime showed a fall in the seeds during the first three weeks of development after which an increase in their contents was found to occur. Potash, on the other hand, showed a continuous decline in the seeds of normal bolls, while it remained almost constant in the seeds of *tirak*-affected bolls after the 5th week of development.

The concentrations of all the four minerals decreased in the lint as it matured.

The following were found to be the important differences between the mineral contents of normal and *tirak*-affected plants on the two soil types :

A low nitrogen content at all stages of growth in the carpels, seeds and lint was a feature of *tirak*-affected bolls on light sandy soils (Fig 17A). The carpets and lint of *tirak*-affected bolls on soils with a saline subsoil on the other hand showed higher nitrogen contents than the corresponding parts of normal bolls at all stages of growth (Fig. 17B). That was not the case with seeds which, like the seeds from light sandy soil, contained less nitrogen than the seeds of normal bolls after the 3rd week of development.

Phosphoric acid contents was found to be below normal in the seeds of *tirak*-affected bolls in the last four stages of develpment from light sandy soils while the same mineral was found to be present in larger concentrations than normal in the carpels from both the soil types and in the seeds of *tirak*-affected plants from soils with saline subsoils (Fig. 17a).

The carpels of *tirak*-affecteed bolls were found to contain less potash at all stages than the carpels of normal bolls and this difference in the potash contents between normal and *tirak*-affected bolls became more pronounced in the final stages of growth (Fig. 18A). Potash continued to increase in the carpels of normal bolls while it remained constant in the carpels of *tirak*-affected bolls during the last three

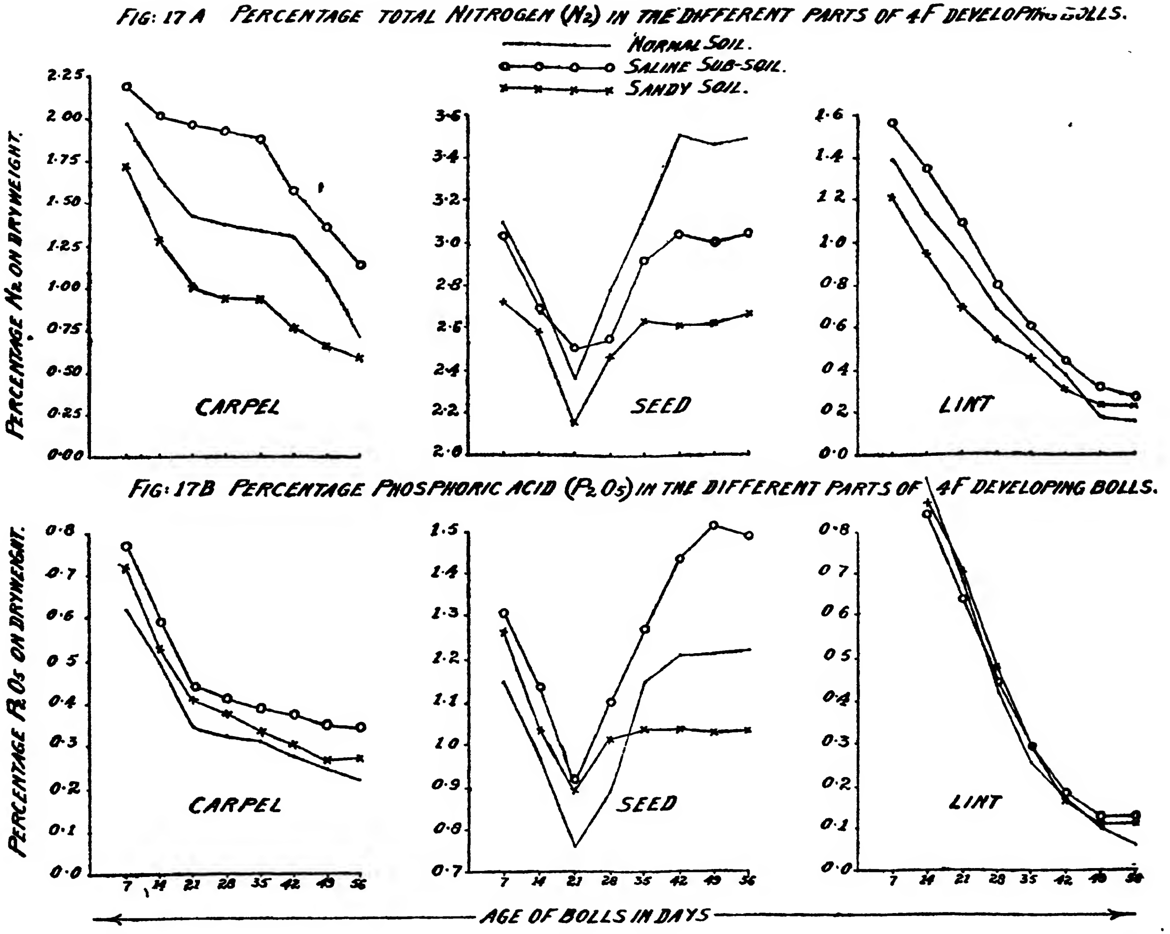

FIG. 17. Percentage of (A) total nitrogen and (B) phosphoric acid in the carpels, seeds and lint of bolls from normal plants and from *tirak*-affected plants on the two soil types, at different stages of development.

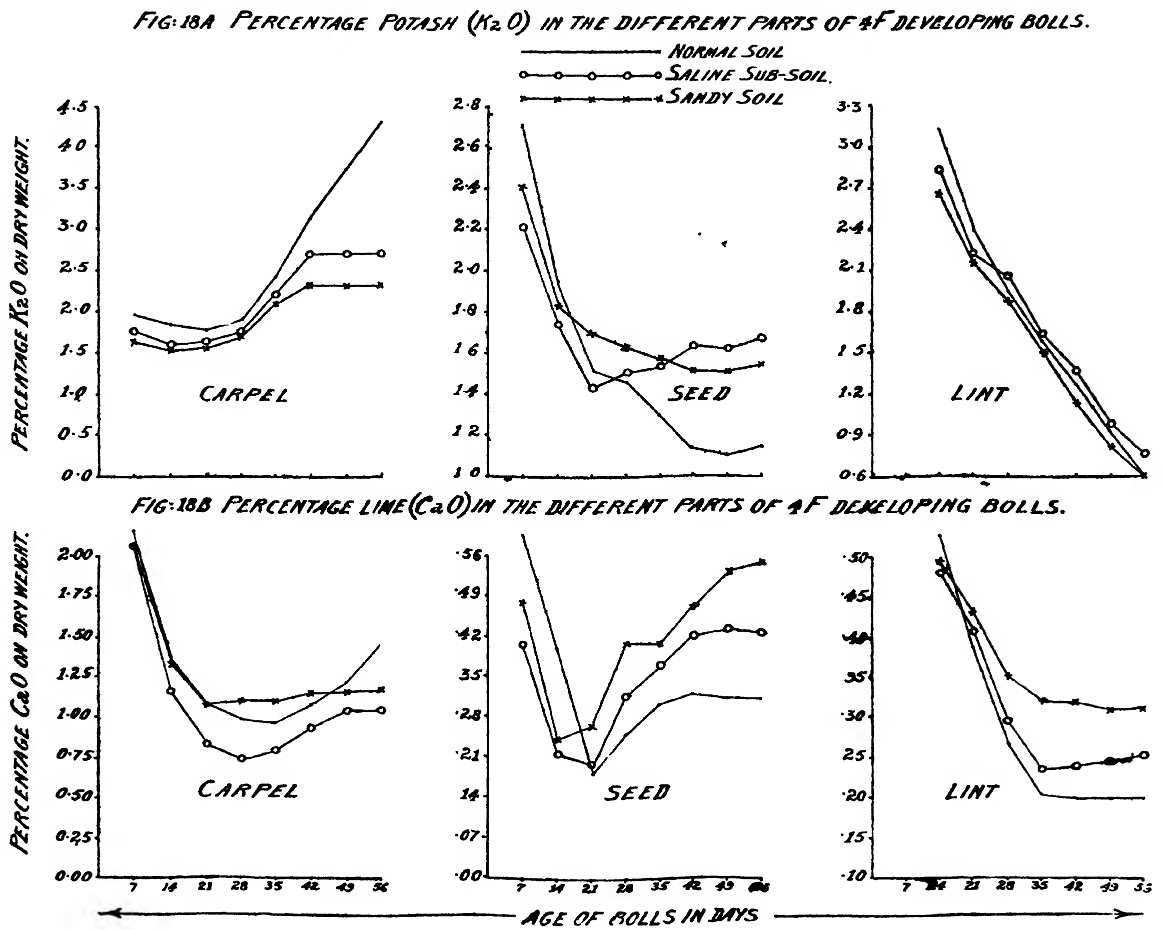

FIG. 18. Percentage of (A) potash and (B) lime in the carpels, seeds and lint of bolls from normal plants and from *tirak*-affected plants on the two soil types, at different stages of development.

weeks of boll development. The potash content of the seeds progressively declined in the normal bolls while it ceased to decrease in the seeds of *tirak*-affected bolls in the later stages of growth.

The lime contents of the seeds and lint in the later stages of growth were higher in *tirak*-affected bolls than in normal bolls (Fig. 18B).

A low potash content in the carpels and a low nitrogen and high potash and lime contents in the seeds were the common features in which *tirak*-affected bolls differed from normal bolls.

As the immaturity of seeds occurred on two different soil types it was possible that the chain of events leading to the development of the common symptom on the two soils may be quite different. It may also be mentioned here that the intensity of *tirak*, *ie.*, the degree of immaturity of seeds was greater on light sandy soils than on soil with saline subsoils. From the results discussed above and represented in Figures 17 and 18 a greater disturbance in the mineral uptake was also noticeable in the bolls from light sandy soils than in the bolls from saline subsoils.

From the results discussed above it was clear that a general deficiency of nutrients was found to occur in cotton plants on light sandy soils. It has already been demonstrated by Dastur (1941), *vide* Chapter III that the application of nitrogen in the form of sulphate of ammonia to light sandy soils ameliorated *tirak* occurring on such soils. It was also shown, though not very conclusively, that when nitrogen was applied, there was an increase, in the uptake of potash and lime by the plants along with that of nitrogen. It, therefore, appeared probable that the uptake of potash and lime was influenced by the level of nitrogen in the soil. The deficiency of potash in the leaves and bolls and of lime in the leaves on light sandy soils may thus arise indirectly on account of a deficiency of nitrates in the soil. It was, therefore, undertaken to establish this point.

The leaves of plants from plots in a field experiment where potash was applied at the rate of 200lb. of K_2O per acre were analysed for potash along with the leaves of plants from control plots where potash was not applied. Five-plant sample was taken for analysis from five control and five treated plots. The leaves from each plot were separately dried and analysed for potash.

TABLE XXIII

Percentage of potash in the leaves of control plants and of plants treated with 200 lb. of K_2O as potassium sulphate per acre

Treatment	1	II	III	IV	V	Mean	S. E.
Control ..	2.82	3.25	2.92	3.49	2.97	3.09	0.059
200 lb. of K_2O p.a. ..	2.96	3.27	2.63	3.64	2.85	3.07	

Direct applications of potash did not increase the potash uptake by the plant as no differences were noticed in the potash contents of the leaves of the control and treated plants. In addition the measurements of boll weight (*i.e.*, the weight of seed cotton per boll indicated no increase in the maturity of seeds of plants in plots treated with potash. Thus *tirak* condition was not ameliorated

The application of nitrogen in the form of sulphate of ammonia was found to ameliorate *tirak* and to increase the yields. It was therefore undertaken to determine the potash contents of the leaves and of the carpels from the control plots and from plots treated with 50 lb. of nitrogen in the form of sulphate of ammonia. Leaves of 5 plants from four control and four treated plots were taken for analysis.

TABLE XXIV

Percentage of potash in the leaves and carpels of control plants and of plants manured with sulphate of ammonia in light sandy soils

Plot No.	Leaves		Carpels	
	Control	Treated with 50 lb. N.	Control	Treated with 50 lb. N.
1	2.36	3.26	3.20	4.27
2	2.76	3.22	3.04	4.62
3	3.06	3.76	3.11	5.28
4	2.63	3.64	3.26	4.86
Mean	*2.70*	*3.47*	*3.15*	*4.76*
S. E.	0.085		0.159	

The potash contents of the leaves and the carpels of plants manured with 50 lb. nitrogen in the form of sulphate of ammonia were significantly higher than the potash contents of the leaves and carpels of unmanured plants (Table XXIV). It has already been shown that when nitrogen was applied, the nitrogen content of the leaves of manured plants was significantly greater than the nitrogen content of the leaves of unmanured plants at the same stage of development (Dastur, 1941)—(*vide* Table V in Chapter III). There was also an increased uptake of lime as revealed by the analysis of the leaves of manured and unamanured plants. The results clearly suggest that potash and lime are not deficient in the light sandy soil but their uptake was lessened on account of the deficiency of nitrates in the soil. If the deficiency of nitrogen was made up by artificial applications, the uptake of these minerals was greatly increased.

The application of nitrogen to light sandy soils was found to increase significantly the bearing, *i.e.*, the number of bolls per plants (Dastur & Mukhtar Singh, 1943 and 44) (*vide* Chapter VIII). Further investigations have shown that nitrogen had no direct relation with the seed maturity. In a field where the soil was light sandy as well as saline in the subsoil, *i.e.*, where both *tirak* promoting soil conditions were present, application of sulphate of ammonia was found to increase the boll number per plant but did not reduce the immaturity of seeds as compared with the boll number and seed immaturity found in the plants from the control plots. The leaves of plants from treated plots did not exhibit the external symptoms of *tirak*, *viz.*, premature yellowing and shedding but the bolls contained partially and fully immature seeds (Dastur, Mukhtar Singh and Sucha Singh, 1944) (*vide* Chapter VIII). A significant increase in the boll number was noticed as a result of the application of nitrogen in the form of sulphate of ammonia to such lands and added nitrogen was utilized for boll production and was not used for increasing the seed maturity.

The application of sulphate of ammonia to sandy loams (not deficient in nitrogen) with saline subsoils did not either increase the boll number or the maturity of seeds (Dastur and Mukhtar Singh, 1942) as compared with the boll number and the seed maturity found in plants of the control plots. As nitrogen deficiency in plants on such soils did not occur, no further increase in boll number per plant on account of nitrogen application was registered. Applications of potash did not either increase the boll number or seed maturity.

Several important conclusions were reached from the results of chemical investigations of *tirak*-affected and normal plants and of investigations carried out in fields where soil conditions were properly determined. (1) Nitrogen applications to light sandy soils directly increased boll production and indirectly the seed maturity. An increased uptake of nitrogen from the soil was accompanied by an increased uptake of other minerals like potash and lime. (2) Direct applications of potash had no effect on boll number or seed maturity. There was no increase in the potash up-take by the plant when potash was added to light sandy soils. (3) Application of nitrogen to light sandy soils with a saline subsoil increased boll production but had no effect on seed maturity. Direct applications of potash to such soils failed to produce any effect on boll production or seed maturity. There was no increase in the potash uptake by the plants when the fertilizer was added to such soils. (4) Applications of nitrogen or potash to sandy loams with saline subsoils had no effect on either boll production or seed maturity. (5) In no case the application of lime was found to have any ameliorative effect on *tirak* on any soil type.

The results clearly indicated that there was no direct deficiency of potash or lime on the two soil types where *tirak* occurred. This fact was further confirmed by the determinations of exchangeable calcium and potassium from the soil under normal crops and from soils under *tirak*-affected crops. No differences in either exchangeable calcium or potassium in the soil under normal and *tirak*-affected crops were found to be present.

A direct deficiency of nitrogen on light sandy soils reduced the uptake of potash on such soils. The case was different with soils with saline subsoils where a direct deficiency of nitrogen was not found to occur. In the former case immaturity of seeds was reduced by the application of nitrogen while that was not found to be the case in the latter type of soil. It, therefore, appeared probable that the immaturity of seeds was associated with the low potash content of the leaves and carpels of *tirak*-affected plants. Though the leaves of *tirak*-affected plants contained less lime than the leaves of normal plants, the carpels of *tirak*-affected bolls from light sandy soils did not show any deficiency of lime.

The association of immaturity of seeds with low potash content has already been known in case of other crop plants. Russell (1937) has pointed out that if potassium was deficient, grains of cereals did not mature. Neal and Gilbert (1935) showed that the application of potash remedied the disease of cotton known as 'cotton rust' or 'potash hunger' where the seeds remained immature. Skinner and Pate (1925) found an increase in boll weight as a result of potash application to fine sandy soils. A decrease in the weight of seeds was reported by Wood (1934) when potash was omitted from manurial experiments. Schuster (1927) reported that soybean plants grown with deficient potash supply produced small and immature seeds with low oil contents.

The cotton plants on soils with saline subsoil showed symptoms of physiological drought at the fruiting stage. The leaves drooped and were gradually shed. Here

it was not primarily a case of a deficiency of nitrogen as the leaves did not show the symptoms of nitrogen starvation, *viz.*, premature yellowing. The application of sulphate of ammonia did not produce any effect on seed maturity. The leaves drooped and were shed where even nitrogen was applied. It is probable that the roots in saline layers of the subsoil did not normally function and the absorption of water and salts was interfered with. The leaves showed low nitrogen and lime contents at all stages of growth and a drop in the potash content from the flowering stage.

Though nitrogen was found to be low in the leaves, no deficiency of nitrogen in the carpels of bolls was found to occur. Though there was an accumulation of nitrogen in the carpels, the potash content was below normal. Thus *tirak*-affected bolls from both the soil types showed a low potash content both in the leaves and carpels and potash appeared to be related to immaturity of seeds.

The deficiency of potash in the carpels of *tirak*-affected bolls was again confirmed by analysing the carpels of bolls from normal and *tirak*-affected plants. The choice of plants was perfectly random irrespective of soil conditions. The normal and *tirak*-affected plants were collected from different fields. The bolls from normal and *tirak*-affected plants were separately analysed.

TABLE XXV

Percentage of potash in the carpels of normal and tirak affected bolls

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Mean
Normal bolls	4.93	4 51	4 22	4.61	4 17	3 76	4.37	4 84	4 38	4.33	4.22	4.45	4.44
Tirak-affected bolls	2.61	2 22	2 34	2.06	2.37	2.85	2 94	2.81	2.75	2.83	2.86	3.04	2.64
	S. E. 0.095												

The potash content of the carpels of *tirak*-affected bolls was found to be significantly lower than the potash content of the carpels of normal bolls (Table XXV). The differences between nitrogen contents of the carpels of normal and *tirak*-affected bolls were not constant. In some cases the nitrogen content of the carpels was found to be higher and in other cases lower in *tirak*-affected bolls than the nitrogen content of the carpels of normal bolls depending on the nature of the soil type from where the sample was collected.

The shift in the time of sowing of cotton from the month of May to the month of June has been found to be the best remedy for *tirak* on soils with saline subsoil. The delay in sowing is accompanied by a reduction in the vegetative growth of the crop which does not suffer from a condition of physiological drought on such soils. The leaves do not droop and the seeds are properly matured in the bolls (Dastur and Mukhtar Singh, 1942). The ameliorative effect on *tirak* is found to be accompanied by a normal uptake of nutrients. The absence of drooping itself indicates normal absorption of moisture. The leaves of the May-sown and the June-sown plants on normal soils and on soils with a saline subsoil were analysed, at fortnightly intervals from the early stages up to maturity for nitrogen, phosphoric acid, potash and lime (Fig. 19A, B). The nitrogen, potash and lime contents of the leaves of the June-sown plants on soil with saline subsoil were higher at all stages of growth than those of the leaves of the May-sown plants. There were no such marked differences in the nitrogen, potash and lime contents of the leaves of the June-sown and the May-sown

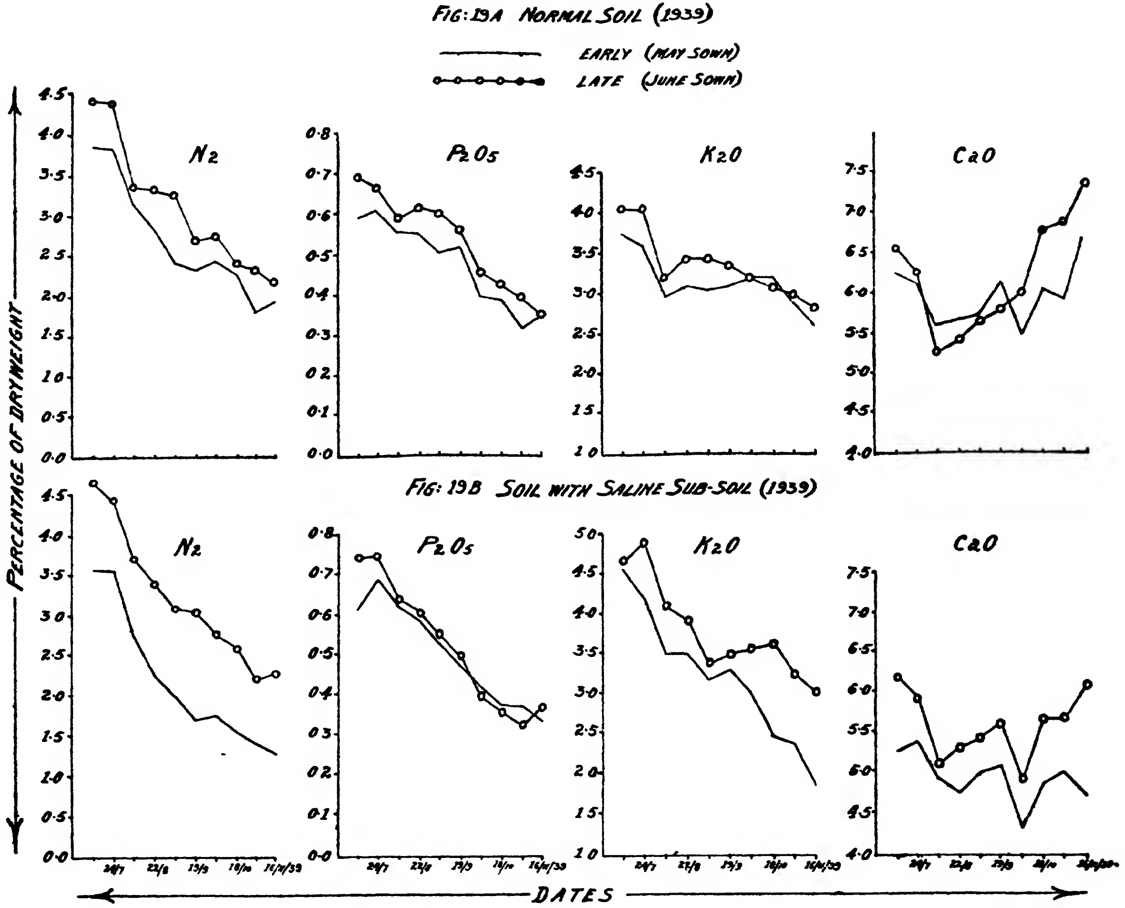

FIG. 19. Percentage of total nitrogen, phosphoric acid, potash and lime in the leaves of early sown and late sown plants at different stages of growth on (*A*) normal soil and (*B*) on soil with saline subsoil.

plants on normal soil. The results, therefore, indicate that a June-sown crop is able to function normally on soils with a saline subsoil, and is able to obtain its normal requirements of water and salts.

(*v*) Protein Metabolism of Bolls

A deficiency of potash or nitrogen had already been known to cause a reduction in the synthesis of proteins and to an accumulation of soluble forms of organic nitrogen, especially in the form of amino acids and amides. Tomato plants when starved of potash were found by Burrell (1926) richer in soluble nitrogen, especially amino acids, than the control plants. Engel (1929) found a similar accumulation of soluble forms of nitrogen and a reduction in total N and protein N when nitrogen was deficient. Philips, Smith and Dearborn (1934) confirmed the findings of Burrell (1926) on the tomato plant. An accumulation of the degraded products of proteins was found to occur when potash was deficient. Richards and Templeman (1936) and Richards (1938) determined the changes produced in the protein and carbohydrate metabolism of barley when nitrogen, potash or phosphorus was supplied in inadequate quantities, and found that a potash deficiency caused an accumulation of amino acids and amides and a decrease in proteins and also to an accumulation of nitrates in the later stages of growth. In the case of nitrogen starved plants a fall in the level of proteins was found to occur. Gregory and Sen (1937) have concluded that a potash deficiency caused an increase in amino acids and a nitrogen deficiency caused a decrease in proteins. Similar results were also obtained by Nightingale (1936 and 1937).

The results of the previous workers clearly indicate that potash deficiency caused some disturbance in the protein metabolism of plants. It was, therefore, necessary to see if similar accumulations of non-protein nitrogen and a decrease in protein nitrogen occurred in *tirak*-affected bolls. Such a study would confirm the conclusion that a potash deficiency was causing the immaturity of seeds by causing a disturbance in the synthesis of proteins in seeds.

The total N, protein N and soluble non-protein N were determined at weekly intervals from the carpels, seeds and lint of *tirak*-affected bolls from the two soil types and of normal bolls from a normal soil. The soluble non-protein nitrogen was further analysed for soluble organic and inorganic fractions. Amino N, amide N, diamino N, ammoniacal N and nitrate N were determined by standard methods given in the Appendix at the end of the Chapter. The results of the total N, protein N and soluble non-protein N in the carpels and the seeds are graphically represented in Fig. 20.

Though the trends in the total and protein N contents of the carpels and seeds of bolls of normal and *tirak*-affected plants were similar (Fig. 20) there were marked differences in the actual quantities of each found at different stages of growth. The total N and protein N declined in the carpels as the bolls developed but in the case of the seeds the total N and protein N began to increase after the 3rd week of development. The concentrations of total N and protein N were highest in the carpels of *tirak*-affected bolls from soil with saline subsoil, medium in the carpels of normal bolls and the least in the carpels of *tirak*-affected bolls from light sandy soils. A nitrogen deficiency was therefore evident in the bolls from light sandy soils while an accumulation of nitrogen occurred in the carpels of bolls from saline soil. The case with protein N content of seeds was different. The protein N content was highest in the seeds of normal bolls, medium in the seeds of bolls from saline soils and the least again in the seeds of bolls from light sandy

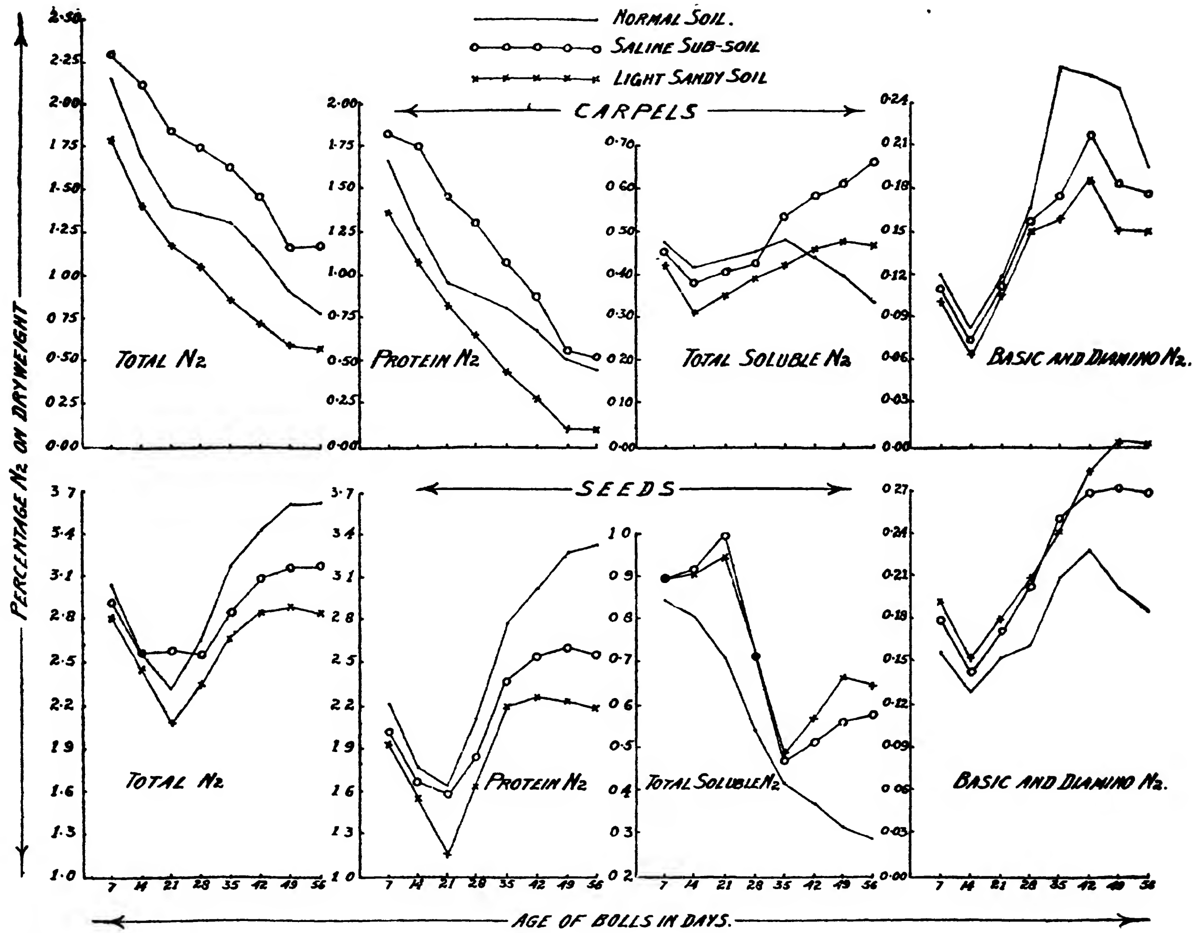

Fig. 20. Percentage of total N, protein N and soluble non-protein N in carpels and seeds of normal bolls from normal sandy loams and of *tirak*-affected bolls from saline sandy loam and light sandy soils at different stages of development.

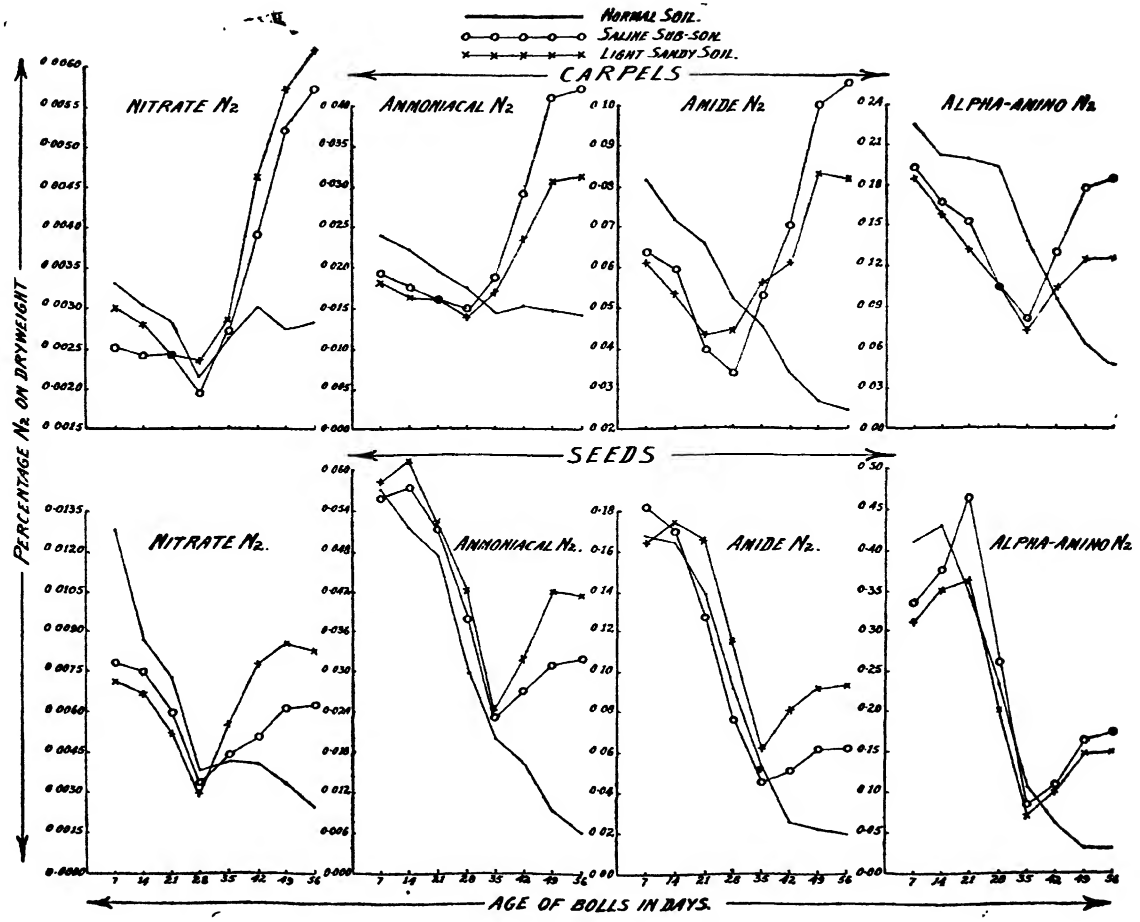

FIG. 21. Percentage of nitrate N, ammoniacal N, amide N and amino N in the carpels and seeds of normal bolls from normal sandy loams and of *tirak*-affected bolls from saline sandy loam and light sandy soils.

soil. Thus the seeds of *tirak*-affected bolls showed a low protein content as compared with the protein content of the seeds from normal bolls. The proteins did not increase in the seeds of *tirak*-affected bolls in the last three weeks of development, while proteins continued to be synthesised in the seeds of normal bolls upto the last week of development. It may be pointed out that the potash content of the carpels of *tirak*-affected bolls also remained constant in the last three weeks of development, while it continued to increase up to the last stage of development in the carpels of bolls from normal plants.

The trends in the total soluble N contents of the carpels and seeds of normal and *tirak*-affected plants also showed differences. The soluble N in the carpels of normal bolls began to decrease from the 5th week while it showed an increase up to the last stage of development in the carpels of *tirak*-affected bolls (Fig. 20). A continuous decline in the soluble N in the seeds of normal bolls occurred from the 1st week up to the last week of development while the same again increased in the seeds of *tirak*-affected bolls from the 5th week. The accumulation of soluble N in *tirak*-affected bolls preceded the cessation of the protein synthesis as no increase in the protein content occurred from the 6th week. The protein metabolism in the bolls of *tirak*-affected plants did not follow the normal course after the 5th week.

A study of the diamino N-contents of the carpels and seeds suggested that the synthesis of proteins in *tirak*-affected bolls ceased at the diamino stage (Fig. 20). The diamino N in the seeds of normal bolls was markedly higher in the last four weeks than that of the seeds of *tirak*-affected bolls even though the total soluble N (which included diamino N) was lower in the seeds of normal bolls during the same peirod. The soluble N in the seeds of normal bolls therefore consisted mainly of diamino N which was being converted into proteins.

The remaining fractions of soluble N in the seeds and carpels of normal and *tirak*-affected bolls showed similar differences (Fig. 21). Nitrates, ammonia, amino acids and amides accumulated from the 5th or the 6th week in the seeds and carpels of *tirak*-affected bolls while these forms of soluble nitrogen (except nitrates in the carpels) showed a continuous decline in the carpels and seeds of normal bolls (Fig. 21).

The accumulation of soluble nitrogen in the carpels and the seeds indicated that the synthesis of proteins ceased in *tirak*-affected bolls from the 6th week of development as from that stage the soluble nitrogen was not converted into protein nitrogen. Total soluble nitrogen in the seeds of *tirak*-affected bolls was at a higher level than the total soluble nitrogen in the seeds of normal bolls at all stages of growth indicating that the protein synthesis was not proceeding at the same speed in *tirak*-affected bolls as it did in normal bolls. The cessation of the protein synthesis in the seeds also caused an accumulation of the different soluble nitrogen fractions in the carpels.

It was evident from the trends in the concentrations of soluble N and protein N in the seeds that the secondary synthesis of proteins occurred from the soluble forms of nitrogen as the concentration of the former decreased and that of the latter increased in the seeds as the bolls matured. The soluble forms of nitrogen travelled from the leaves to the bolls as it was shown earlier that the concentration as well as percentage distribution of nitrogen decreased in the leaves from the onset of the reproductive phase and increased in the bolls as they developed (Figs. 12 & 14) (Dastur & Ahad, 1941). The supply of soluble organic nitrogen greatly declined

from the 6th week in *tirak*-affected bolls and this fall coincided with a decline in the absorption of potash. Lack of potash caused a cessation in the protein synthesis and whatever small amounts of soluble nitrogen that reached the bolls remained unconverted into proteins and it remained accumulated mostly in the form of diamino and monoamino acids and amides.

It was pointed out in Chapter V that the dry weight of bolls from *tirak*-affected plants did not show any increase from the 6th week and it remained constant (Fig. 9). In the case of normal bolls the increase in the dry weight continued up to the 8th week. Thus the growth of bolls and the synthesis of proteins in *tirak*-affected plants ceased at the same stage.

(*vi*) Synthesis of Oil in Relation to Carbohydrates

It was clear from the results outlined above that the potash metabolism, the protein synthesis and the growth of bolls in *tirak*-affected plants were interrelated and interdependent. In the case of *tirak*-affected plants the cotyledons of immature seeds were thin and papery. They did not get filled with oil. It would, therefore be interesting to determine what effects on the synthesis of oils were produced by the cessation of the synthesis of proteins. It was necessary to determine the stage at which the synthesis of fats in the seeds of *tirak*-affected bolls began to get depressed and to know if the depression in the synthesis of fats occurred at an earlier or at a later period than the stage at which the synthesis of proteins was inhibited in the seeds. It was also necessary to determine the physical and the chemical constants of the oil produced in the seeds of normal and *tirak*-affected bolls to see if there was any difference in the nature of oil produced in the two cases.

This study of oil metabolism of bolls would be incomplete if the trends in the carbohydrate contents were not, side by side, determined, as it was known that oil was formed from carbohydrates. The carbohydrate analysis of the developing bolls may show if they were acting as limiting factors in the seed maturation of *tirak*-affected plants.

Caskey and Gallup (1931) have already shown that the oil content increased and sugars decreased in all parts of the boll as development proceeded. The period of maximum oil formation was found to lie between the 21st and the 30th day of boll development. Similar relationship between the oil and the sugar contents had been found by Gerber (1897) in the case of walnut and almond, by Ivanow (1911, 1912) in the case of flax and rape seeds, by Rushkovski (1930) in the case of sun-flower seeds, by Eyre (1931) and Johnson (1932) in the case of flax, and by Sahasrabuddhe and Kale (1933) in niger seed. Reaves and Beasley (1935) who studied the development of cotton embryo found that sugars were present from the very beginning of embryonic development while oil appeared from the third week.

The percentage of oil in the developing seeds from the bolls of normal and *tirak*-affected plants was determined at weekly intervals. The melting point, the refractive index, the saponification, iodine and acid values of the ether extract of each week were separately determined by the standard methods given in the Appendix at the end of the Chapter.

The carbohydrate analysis of the carpels, seeds and lint of bolls from normal and *tirak*-affected plants was also made. The reducing sugars, disaccharides and starch were separately estimated by the methods given in the Appendix at the end of the Chapter. In addition the lint was analysed for *alpha* cellulose, *beta* cellulose and *gamma* cellulose.

CHAPTER XXVI

Characteristics of oil from normal and tirak-affected plants

Age of bolls	Iodine Value			Saponification Value			Acid Value			Melting Point C°			Refractive Index		
	Normal	Saline	Sandy	Normal	Saline	Sandy	Normal	Saline	Sandy	Normal	Saline	Sandy	Normal	Saline	Sandy
7 days	36.45	37.81	36.65	155.20	151.80	153.80	56.40	54.02	54.43	52.0	51.0	50.4	1.485	1.486	1.486
14 days	34.86	35.31	35.27	158.80	156.60	158.50	57.05	52.42	55.40	50.5	51.5	51.0	1.485	1.485	1.485
21 days	37.05	62.88	38.72	157.60	170.50	157.30	55.92	38.93	54.15	51.0	10.0	50.0	1.485	1.476	1.485
28 days	85.70	83.38	82.62	179.30	177.10	174.60	31.37	29.16	32.28	7.0	9.0	10.0	1.475	1.475	1.475
35 days	96.22	92.25	91.26	183.20	182.50	182.40	18.64	17.48	19.11	3.5	3.5	4.0	1.474	1.474	1.475
42 days	102.50	96.30	95.50	189.50	185.70	183.10	8.74	10.51	11.64	2.2	2.8	2.5	1.474	1.474	1.474
49 days	108.40	101.75	100.82	193.40	186.20	186.60	2.55	7.64	8.65	2.0	2.5	2.3	1.474	1.474	1.474
56 days	109.5	101.20	100.20	194.70	187.80	188.40	0.45	5.45	6.86	2.1	2.4	2.2	1.473	1.474	1.474

The results of oil contents and the different constants of oil are given in Fig. 22 and Table XXVI respectively. The ether extract of the seeds in the first three weeks of development consisted of a waxy substance of a high melting point fluctuating between 52° to 55°C. The real oil formation started from the fourth week of boll development in the case of normal plants and of *tirak*-affected plants on light sandy soils while oil appeared a week earlier in the seeds of *tirak*-affected plants on soils with saline subsoil. The oil formation ceased in the sixth week in the seeds of *tirak*-affected plants while it continued to increase up to the eighth week in normal plants, *i.e.* up till the bolls opened. The quantity of oil formed per 100 gm. of seeds in *tirak*-affected plants was less than in the seeds of normal plants.

The melting point of the ether extract was gradually lowered as the seeds developed till it reached a value of 2°—3° C. at maturity in the seeds from normal as well as *tirak*-affected plants. There was an increase in the saponification and iodine values of the ether extract as the seeds matured indicating that the fatty acids of low molecular weights and the unsaturated fatty acids in the oil increased as the seeds developed. The values of these constants of ether extract were slightly lower in the seeds of *tirak*-affected plants than in the seeds of normal plants. The acid value of the extract was found to decrease as the seeds developed indicating a decrease in free fatty acids. The ether extract of the seeds of *tirak*-affected plants showed slightly higher amounts of free fatty acids than the ether extract of the seeds of normal plants.

Thus except for minor differences in the different constants of oil, the nature of the oil formed in normal and *tirak*-affected plants appeared to be the same.

The reducing sugars, disaccharides, starch and oil contents of the seeds from normal and *tirak*-affected plants are given in Fig. 22. The most noticeable feature was the fall in carbohydrates and a rise in the oil content as the seeds matured. The reducing sugars and starch were present in larger amounts than disaccharides which were present in very small amounts.

The carbohydrate analysis of the carpels (Fig 23) showed that the reducing sugars were present in largest amounts. They showed a rise in the first two weeks after which they declined rapidly. The starch and disaccharides showed a decline at a later stage.

The results described above definitely indicated that proteins and oil were formed from carbohydrates. The reducing sugars appeared to be the main translocatory form of carbohydrate utilized in the formation of proteins and oil in the seeds as this kind of sugar declined both in the seeds and carpels as development proceeded. The starch and disaccharides found in the carpels and seeds may be regarded as temporary storage products resynthesised from the reducing sugars. These higher forms of carbohydrates appeared to be reconverted into reducing sugars as the latter were being utilized in the synthesis of protein and oil.

(*vii*) Analysis of Lint

The carbohydrate analysis of the lint showed that the reducing sugars were present in largest amounts in the early stages of development (Fig. 24). 50% of the dry weight of lint consisted of reducing sugars in the first week of lint development. Disaccharides were found to be present in minute quantities. The reducing sugar declined as the lint matured until they were almost absent in the fully mature fibre. Similar decrease in the reducing sugars in the lint as it matured was found by Jack and Forest (1940).

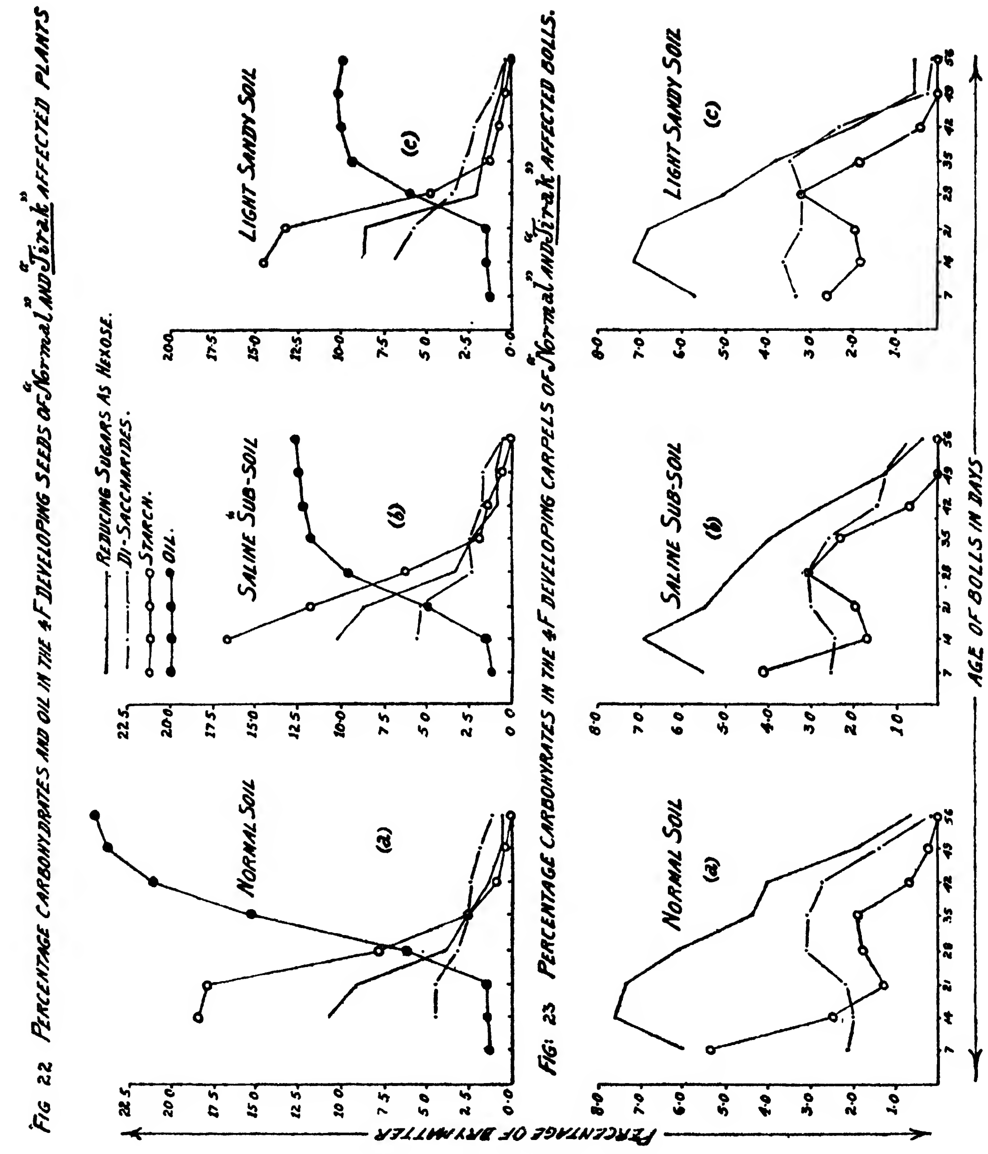

FIG. 22. The percentages of reducing sugars, disaccharides; starch and oil in the seeds of bolls at different stages of development from normal plants and *tirak*-affected plants from the two soil types.

FIG. 23. The percentages of reducing sugars, disaccharides and starch in the carpels of bolls at different stages of development from normal plants and *tirak*-affected plants on the two soil types.

The progressive decline in the reducing sugars was accompanied by an increase in the cellulose content of the lint. Thus it was evident that cellulose was formed from the reducing sugars. This was not improbable as the cellulose molecule was made up of a number of dehydrated glucose molecules.

The analysis of cellulose of the lint revealed that it was mainly composed of *alpha* cellulose, while *beta* cellulose and *gamma* cellulose were present in very small amounts (Fig. 24).

The cellulose content of lint from *tirak*-affected plants was found to be less on percentage dry weight basis than the cellulose content of the lint from normal plants. The lint in the case of normal plants contained 90.60% of cellulose, while the lint from *tirak*-affected plants from the soil with saline subsoil and the light sandy soils contained 82% and 76% of cellulose respectively.

The lint of *tirak*-affected plants is though known to be weak, it is not found to suffer in length. The decreased cellulose content of the lint in *tirak*-affected plants indicated that the fibre did not grow in thickness by the deposition of cellulose on the original cell wall to the same extent as it did in the case of normal plants. The celullose contet nof the lint was, therefore, lowered in the former as revealed by the technological tests carried out on the lint of the normal and *tirak*-affected plants (Table XXVII).

TABLE XXVII

Technological properties of lint from normal and tirak-affected plants

	MATURITY COUNTS				
	Length in inches	Fibre wt. 10^{-6} gm.	% of mature fibres	% of half mature fibres	% of immature fibres
Normal plants ..	0.79	0.172	76	10	14
Tirak-affected plants on soils with saline sub-soil	0.71	0.128	48	12	40
Tirak-affected plants on light sandy soils ..	0.71	0.114	38	18	44

There was no appreciable difference in the lint length but there was marked difference in the fibre weight per unit length. The fibre from normal plants weighed

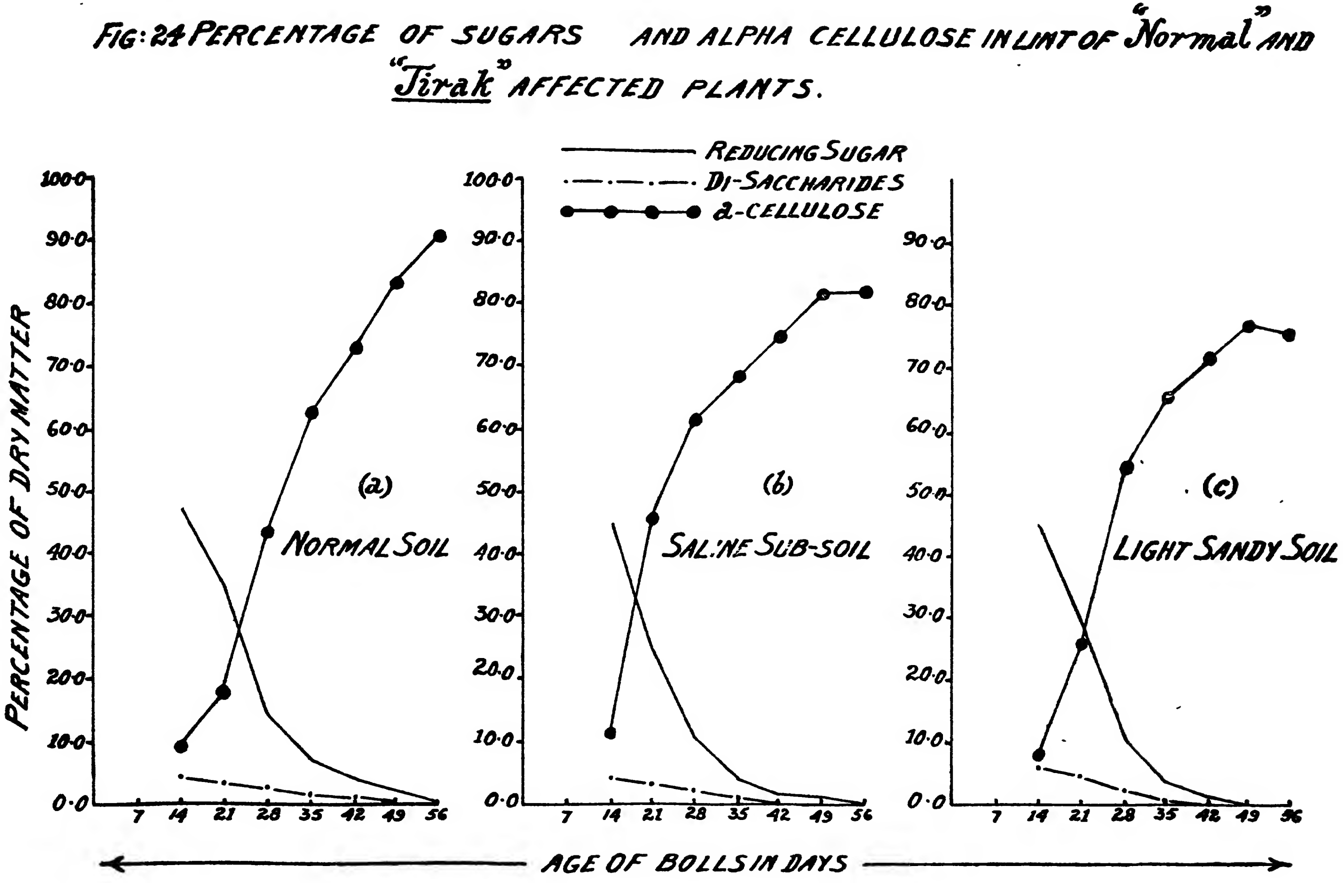

FIG. 24. The percentage of reducing sugars, disaccharides and alpha cellulose in lint from normal plants and *tirak*-affected plants on the two soil types.

more per unit length than the fibre from *tirak*-affected plants. Thus the conclusion that the lint of *tirak*-affected plants did not grow in thickness by the deposition of cellulose to the same extent as it did in the case of normal plants was again confirmed. This was also clear from the maturity counts given in Table XXVII. The lint of *tirak*-affected plants was found to contain a higher proportion of immature fibres than the lint from normal plants. The immaturity of fibres can be associated with the immaturity of the seeds as once the seeds ceased to develop, further growth of the fibres on the immature seeds would automatically cease.

(*viii*) Conclusions

The study of the physiological chemistry of *tirak*-affected cotton plants on the two types of soils showed three common biochemical features. They were: (1) low potash content in the leaves and carpels, (2) depressed protein synthetic activity and (3) decreased oil formation in the seeds. No differences in the carbohydrate contents of either the carpels, seeds or lint of the normal and *tirak*-affected plants were found to exist. It was, therefore, clear that an insufficiency of the carbohydrate supply was not responsible for a depression in the protein and the oil synthesis in the seeds of *tirak*-affected plants. There was also evidence to show that nitrogen was not acting as a limiting factor in the synthesis of proteins in *tirak*-affected bolls. Though the nitrogen content of the leaves of *tirak*-affected plants was lower than that of the leaves of normal plants, the case was different with the bolls. An accumulation of nitrogen in the bolls from *tirak*-affected plants from soil with saline subsoil was found to occur though the synthesis of proteins was depressed. It was also demonstrated in Chapter III that the immaturity of seed in *tirak*-affected plants on light sandy soils was not related to nitrogen content. Thus low potash may be reckoned as the starting point of the internal disorder setting in *tirak*-affected plants. The low potash content gave rise to a depression in the synthesis of proteins and consequently to the development of immature seeds with immature fibre. Many instances have been known and already quoted before where potassium deficiency was found to inhibit the synthesis of proteins in plants and to cause immaturity of seeds.

The deficiency of potash in *tirak*-affected crop on the two soil types developed in a different manner. It was shown that the uptake of potash by the crop on light sandy soils was reduced on account of a deficiency of nitrogen in the soil. The deficiency of potash in *tirak*-affected crop on soils with saline subsoils on the other hand developed as a result of the physiological drought which interfered with the normal absorption of nutrients. The common symptom, *viz.*, immaturity of seed, therefore, developed in plants on both soil types though the symptoms exhibited by the leaves of *tirak*-affected plants on the two soil types were found to differ.

(iv) METHODS USED IN PLANT ANALYSIS

(a) *Minerals :—*

Estimation of total nitrogen.– kjeldahl salicylic acid method modified to include the nitrate nitrogen (Official).

Estimation of Phosphoric acid.—Phospho-ammonium molybdate volumetric method (Official—modified).

Estimation of Potassium.—Cobaltinitrite volumetric method. Milne, G. (1929) J. Agric. Sc. 19 : 541 (modified).

Estimation of Calcium.—Volumetric oxalate method. (Official).

Estimation of Magnesium.—As Magnesium-Pyrophosphate (Official).

Estimation of Sulphur as Sulphate.—Barium sulphate method, modified to include organic sulphur (Official).

Estimation of Chlorine as chlorides.—Titration with silver nitrate—volumetric method (Official).

Estimation of Iron.—Thiocyanate colorimetric method (Official and Tentative.)

(b) *Oils :–*

Estimation of total oil.– Petroleum ether extraction (Standard method).

Estimation of iodine value– Wij's modification of the Hubble's method as given in Jamieson's (1932) 'Vegetable Oil and Fats.'

Estimation of melting point, saponification value, acid value and refractive index : (Standard methods).

(c) *Carbohydrates :–*

Estimation of reducing sugars and total sugars,– Shaffer Somogyi's method modified by Heinze, P. H. and Murneek. A.E., (1940) Research Bulletin No. 314, University of Missouri, Columbia.

(d) *Protein Analysis :–*

Estimation of total nitrogen.– Kjeldahl salicylic acid method modified to include the nitrate nitrogen (Official).

Estimation of total soluble nitrogen.— Leonard, A.O., (1936) Plant Physiol; 11; 25-61.

Estimation of nitrate nitrogen.—Frear, D.E. (1930) Plant Physiol; 5, 359-371.

Estimation of ammoniacal nitrogen.—Schlenker, F.S. (1932) Plant Physiol; 685-695.

Estimation of amide nitrogen.—Tottingham, *et al.*, (1935) Plant Physiol; 10 393-398.

Estimation of Alpha-amino nitrogen.—Van-Slyke's standard method (modified)

Estimation of Diamino and Basic nitrogen.—Phosphotungstic acid method— Leonard, A. O. (1936) Plant Physiol; *11*, 25-61.

CHAPTER VIII

REMEDIAL MEASURES FOR *TIRAK*

It was shown in Chapter III that the application of sulphate of ammonia to light sandy soils prevented the development of *tirak* symptoms in 4F American cotton. Premature yellowing and shedding of leaves did not occur, the opening of bolls improved considerably and the yields of seed cotton also increased. It has been already discussed that *tirak* symptoms also develop on soils with highly saline or alkaline subsoil and it would be shown below that the application of sulphate of ammonia to such soils did not ameliorate *tirak*. This was to be expected as the nature of the disorder that leads to *tirak* condition on this type of soil was different. The plants developed the symptoms of drooping and shedding of leaves and, therefore, the bad opening of bolls was the consequence of a disturbance in their water relations. The application of nitrogen would not, therefore, remedy the trouble.

In the case of the second soil type, the high concentrations of sodium salts occurred at a depth of three feet from the soil surface *i.e.*, the seat of trouble was the subsoil. The application of any remedial measure to counteract the toxic effect of these salts or to wash the salts down from the feeding zones of the roots was, therefore, difficult. To neutralize the toxic effects of sodium salts, gypsum is generally applied but the movement of gypsum in the soil is extremely slow. It would take a number of years and need frequent irrigations and more than one application, varying according to the physical properties of the soil, before gypsum, would reach the saline subsoil. The time and the cost of amelioration would, therefore, make it an almost impracticable proposition. The remedy of washing down the sodium salts from the feeding zones of the roots by means of flooding or rice cultivation was also of limited application as its effectiveness would depend on the thickness of the soil crust containing salts. If the soil crust was only about 5 to 6 feet thick after which the sand layer was present the salts could be washed down to sand layer from which the rise of salts would not occur. In fact such washing down of salts had already been found to occur under irrigation in fields which had sandy layers at a depth of 5 to 7 feet but if the soil crust was of greater thickness the task of washing the salts to the sandy layers would become more and more difficult and there was always a possibility of the salts to rise again.

The soils with saline subsoils were interspersed, not infrequently, with light sandy soils deficient in nitrogen and with those possessing normal subsoils. The application of any remedial measure to ameliorate saline subsoils was thus fraught with difficulties, for such a measure would have to be applied to parts of an area where it was not required. As for instance if flooding was done to wash the salts downwards, it would also leach from the feeding zones of roots, the important nutrients of the non-saline and light sandy portions. This would lower the soil fertility.

In view of the great soil heterogeneity that was found to prevail in the American cotton growing tracts of the Punjab, the remedy for the amelioration of *tirak* should be such that it would ameliorate *tirak* occurring on both the soil types and at the same time it would not adversely affect the growth of the crop on normal lands where *tirak* did not occur.

If a strain of American cotton resistant to the development of *tirak* could be found it would, undoubtedly, be the best way of meeting the situation. All strains of American cottons, as will be shown later, have however been found prone to *tirak*. The only alternative to minimize the damage caused by *tirak* was to place the crop in a position so that it did not suffer from a deficiency either of nitrogen

or of water or both, at the time of fruiting. A reduction in the plant size, was therefore, conceived to be a practical way to attain this end. By reducing its vegetative structure, the crop may be able to function normally on the two soil types and it may not develop *tirak* symptoms.

The most natural way to reduce the plant size was to shorten the vegetative period of the crop by delaying the sowings of cotton for a period to be determined experimentally. The delay in sowings was expected to reduce the size of the crop and its demand for water or nitrogen would consequently be reduced. The cotton sowings generally began in the first week of May and it was considered of interest to study the effect of June-sowings on plant size and consequently on *tirak* on soil with saline subsoils.

(*i*) Amelioration of *Tirak* on Sandy Loam with Saline Subsoil

The field where subsoil salinity was found to be present in patches and where *tirak* was observed in the preceding season, was selected in 1937 for conducting the experiment. The field was divided into 48 sub-plots in December, 1937 (Fig. 7). The following six sub-plot treatments were under comparison: (1) Control, (2) flooding, (3) 1000 lb. of gypsum followed by flooding, (4) 246 lb. of sulphate of ammonia + 287 lb. of super-phosphate at sowing, (5) treatments 3 and 4 together and (6) 10 tons of farmyard manure. Two dates of sowing were allocated to 8 main plots. Early sowing was done on 5—6th May, 1938, and late sowing on 15—16th June, 1938. The details of this experiment have already been published (Dastur and Mukhtar Singh, 1942.)

The crop in each plot was under close observation throughout the season. In September the May-sown cotton plants began to show drooping symptoms irrespective of the other sub-plot treatments mentioned above, while no drooping of leaves occurred in any one of the plots which were sown in June. The drooping of leaves was followed by excessive defoliation in the May-sown crop. The leaves of the plants under the two sowings presented striking differences in colour and appearance at the fruiting stage. They remained dull and blackish-green in the May-sown and were green and fresh in the June-sown.

The date of flowering in the June-sown crop was only shifted forth by 12 days even though the interval between the two dates of sowing was about 40 days. The flowers were mostly aggregated to the tips of branches (Fig. 25) in the May-sown crop, while in the June-sown they were distributed from the lower to the topmost part of each branch (Fig. 26). The results of weight of seed cotton per boll and the yield per plot are given in Table XXVIII below :

Table XXVIII

Average weight of kapas per boll in gm.

	Control	Gypsum	Flooding	NP	Gypsum +NP	F.Y.M.	Mean for sowing dates	Diff.	C. D.
May-sown	1.89	1.95	1.95	1.78	1.86	1.87	1.88	0.42**	0.25
June-sown	2.35	2.20	2.32	2.42	2.29	2.21	2.30	..	..
Average yield in lb. per plot (1/153 acre)									
May-sown	7.5	8.3	9.2	8.2	7.8	7.5	8.1	6.0**	2.33
June-sown	15.3	14.2	14.7	16.4	15.4	13.6	14.1	..	..

** Significant at 1 per cent. level of significance.

FIG. 25. The May-sown 4F American plant showing the aggregation of flowers and bolls at the tips of branches (leaves removed).

FIG. 26. The June-sown 4F American plant showing that the flowers and bolls are well spaced from the lower to the topmost part of each branch (leaves removed).

The performance of the June-sowings (Fig. 28) was markedly superior to that of the May-sowings (Fig. 27) both in regard to the maturity of seeds and the yields. The seeds in the late-sown crop matured better than those in the May-sown crop. The weight of seed cotton per boll in *tirak*-affected plants in the May-sown crop was generally much lower than the value recorded above. In this particular field the salinity in the subsoil was not uniformly distributed over the entire area but was present in patches. The weight of seed cotton per boll on such patches was found to be about one gram. The weight of *kapas* per boll in the June-sown plants, growing under similar conditions of salinity, was much higher than one gram. The yield of the June-sown crop was about 85% higher than that of the May-sown crop. The other treatments given to the soil for remedying the saline subsoils did not produce any effect on *tirak* as can be seen from the Table XXVIII.

Further experiments with June-sowings revealed that though *tirak* was invariably remedied by June-sowings, the increase, in yield did not always occur. In some cases, late June-sowings gave a lower yield as compared with the May-sowing. Yield depends on two characters, (1) the number of bolls produced by the plant and (2) the size of each boll (*i.e.* weight of *kapas* per boll). By deferring sowings to June even though *tirak* was remedied the number of bolls produced was lowered on account of reduction in the size of the plant. Wherever the loss, through boll number, outweighed the gain through boll weight resulting from late sowings, the yields were adversely affected.

The cotton plants in the Punjab are generally sown in rows which are 3 ft. apart from one another. The distance from plant to plant in each row is generally $1\frac{1}{2}$ ft. The reduction in yield caused by a decrease in boll number in June-sowings can be avoided by sowing the crop at 2 ft. distance instead of at 3 ft. The plant to plant distance should also be reduced according to the sowing date in June. As the plants sown in June are smaller in size than the plants sown in May, greater number of plants can be successfully grown in the same area. The disadvantage of reduced boll production per plant could thus be removed by increasing the plant number and in additon *tirak* would be remedied.

June-sowings were tried primarily with the object of reducing the water requirement of the crop at the fruiting stage by cutting down the total transpiring leaf surface. It may, however, be surmised that the leaf area per acre of a closely spaced June-sown crop may equal the leaf area of the May-sown crop spaced at normal distance, and thus little difference might actually result in the water requirement of the two sowings. This was not, however, found to be the case in practice. Actual measurements of the leaf area per plant of the May-sown and June-sown crops were made in 1941-42 cotton season on soils with saline subsoil. These determinations were made on a 5-plant sample from each of the five plots. The maximum leaf area per plant in the May-sown crop was 11809 sq. cm., while the maximum leaf area per plant of the June-sown crop was 4017 sq. cm. Even if the number of plants per acre in the June-sown plots was doubled, the total leaf area per acre would still be less than the total leaf area per acre when the crop was sown in May. The absence of drooping symptoms in the late sown crop, as mentioned already, further confirmed the view that the water requirements of the late sown were adequately met. Even if the total leaf area in the June-sowings were to equal the total leaf area per acre in the May-sowings, the individual was more important from a physiological point of view than the leaf area per acre, so long as the balance between the supply and demand of water of the crop was maintained.

The application of extra water during the fruiting stage appeared to be a possible remedy for lessening the damage caused by *tirak* on soils with saline subsoils as by this method the upper non-saline layers of the soil would be kept sufficiently moist to meet the needs of the crop. Extra water can either be given in the form of heavier* waterings or more frequent waterings than normal. An experiment was, therefore, laid out in the cotton season of 1939-40 to determine the effects of sowing date, spacing, extra watering and nitrogen on the opening of bolls and the yields on a field with a saline subsoil. A 2^4 factorial experiment was designed in which all combinations of $\begin{Bmatrix} d1 \\ d2 \end{Bmatrix} \begin{Bmatrix} s1 \\ s2 \end{Bmatrix} \begin{Bmatrix} w1 \\ w2 \end{Bmatrix} \begin{Bmatrix} o \\ n \end{Bmatrix}$ were tried (d1=crop sown on 14th May, d2=crop sown on 21st June, s1=2ft. × 1½ft., s2=2½ft. × 2½ft., w1=normal watering, w2=heavy watering from mid-August to mid-October and n=50 lb. N in the form of ammonium sulphate applied in August). The layout was 8×8 quasi-latin square (Excpt. No 8—see Appendix at the end of the Chapter IX). An attempt was made to minimise the effects of soil heterogeneity by eliminating two-way systematic soil variations by adopting the method of confounding high order interactions along the rows and columns. The results of the weight of seed cotton per boll (opening) and of yields are given below:

TABLE XXIX

	Treatments.	Weight of *kapas* per boll in gm.	Difference with S. E.	Yield in maunds p. a.	Difference with S. E.	Weight of stems in maunds p. a.	Difference with S. E.
MAIN EFFECTS.	d2 (21/6) ..	1.47	** 0.18±.064	13.82	0.39±1.06	22.92	** —41.17±2.39
	d1 (14/5) ..	1.29		13.43		64.09	
	w2	1.45	* 0 14±.064	15.35	** 46±1.06	45.62	4.22±2.39
	w1 . ..	1.31		11.89		41.40	
	n	1.36	—0.03±.064	13.41	—0.41±1.06	43.15	—0.72±2.39
	o	1.39		13.82		43.87	
	s1	1.43	0.10±.064	15 35	** 3.46±1.06	48.67	** 10.33±2.39
	s2	1.33		11.89		38.34	

D. W. INTERACTION.	d1. (14/5)	d2. (21/6)	Diff. ±.091		d1. 14/5	d2. 21/6	Diff. ±1.50		d1. 14/5	d2. 21/6	Diff. ±3.38
w2 ..	1.42	1.48	0.06	w2 ..	16.77	13.94	—2.83	w2 ..	68.6	22.65	** —45.95
w1 ..	1 15	1.46	** 0.31	w1 ..	10.09	13.70	* +3.61	w1 ..	59.6	23.20	** —36.40
Diff. ..	** 0.27	0.02	..	Diff. ..	** 6.68	0.24	..	Diff. ..	* 9.0	—0.55	..
	±0.091				±1.50					±3.38	

A study of Table XXIX will show that both the ameliorative measures, deferred sowings and heavy waterings, significantly increased the weight of seed cotton per boll, indicating better opening of boll *i.e.* less of *tirak*. The interaction of sowing dates with waterings, D. W. was significant, showing that the opening of bolls in the May-sown crop was greatly improved by heavy watering, while the late-sown crop showed no further improvement in opening by the extra application of water,

* Heavy watering= Plots irrigated again after 24 hours.

FIG. 27. The May-sown 4F crop on sandy loam with saline subsoil showing "badly opened" bolls.

FIG. 28. The June-sown American 4F crop with "well opened" bolls on a sandy loam with saline subsoil.

as the improvement in opening obtained by deferred sowings alone was of a high magnitude. The plants under late sowings did not also require extra water as no disturbance in the water balance occurred in the late-sown crop. This was also indicated by the absence of drooping of leaves in late-sowing.

The generalised effect of spacing on yields was positive and significant, indicating that the yield under close spacing was higher than that under wide spacing. Though the interaction of dates and spacing (D×S) did not come out significant it may be seen that the late-sown crop benefited more by close spacing than the early-sown (Table XXX).

The main effect of spacing derives its significance from the significant effect of close spacing in d2 only, the effect of close spacing under d1 alone being non-significant.

TABLE XXX

	Wt. of seed cotton per boll in gm.				Yield in maunds p. a				Yield in maunds p. a.		
	d1.	d2.	mean.		d1.	d2.	Mean.		d1.	d2	Diff. ±1.50
n= ..	1.26	1.17	1.36	n=	12.81	11.02	13.41	s2=	12.42	11.36	+1.06
o= ..	1.31	1.48	1.39	o=	14.04	13.61	13.82	s1=	14.44	16.27	−1.83
								Diff. (±1.50)	+2.02	+4.91**	

The generalised effect of watering on yields was significant at 1% level of significance and the interaction between sowing date and watering was also significant (Table XXIX). The early sown crop profited considerably by extra applications of water, while no benefit accrued to the late-sown. The increase in yield due to heavy watering in the former was 6.6 maunds per acre, while the increase was practically nil in the latter. Thus extra watering had helped the early-sown crop both in increasing the yields and the weight of seed cotton per boll, while similar advantage from heavy watering was not derived by the late-sown in any case.

The results discussed above clearly indicated that *tirak* occurring on soils which have a saline subsoil could be ameliorated by either reducing the water requirements of the crop by means of deferred sowings or by the application of extra water from the beginning of flowering phase so that the upper non-saline layers may adequately meet the demand of the crop. The first remedy of deferred sowings is to be preferred to the second remedy as the former enables the crop to meet its own demands for water without external aid. The former is also a more practical remedy than the latter as the water supply is usually limited. There was considerable observational and experimental evidence to support the view that the late-sown crop was better adapted to its edaphic and climatic environment than the early-sown (May-sown) crop. The late-sown crop showed no symptoms of water starvation and consequently was able to mature its crop of bolls under saline conditions of the soil or under unfavourable conditions of weather or both. A late-sown plant was thus in physiological equilibrium with its environment and was able to stand the vagaries of weather which many a time was dry and warm during the fruiting period.

It was also a more efficient organism than a May-sown plant. It produced more of seed cotton in proportion to its size than what an early-sown plant did. The latter exhausted itself in the vegetative growth and, by the time bolls were formed, it had already reached a stage of senescence. A slightly higher temperature than normal for a brief spell of three weeks or so was sufficient to upset its metabolic processes on such saline subsoils, for the plant had lost its capacity for adjusting itself to such changes in its environment. No particular advantage was also gained by the sowing of the cotton crop in May even on non-saline soils as the flowering phase did not set in early in the early-sown and if it did, such flowers did not develop into bolls and were generally shed. The onset of flowering was not proportionately delayed as the sowings were delayed; a shift in the date of sowing did not materially influence the main flowering period which occurred in the month of September. Early-sowings will be advantageous only when the flowering period is also considerably prolonged. A long flowering period would enable the crop to mature a larger number of bolls than what they do. But as the matters stand the early-sown crop becomes unbalanced with a long vegetative phase and a short reproductive phase. This lack of balance between the two phases results in a low efficiency in the production of seed cotton.

The June-sown crop however, suffered from one disadvantage as compared with the early-sown crop. As the vegetative phase was shortened the bearing points were reduced, resulting in reduced number of bolls. But this disadvantage was counteracted by closer spacing of plants, *i.e.*, by increasing the number of plants per acre. This measure made up for the decrease in bearing of the late-sown plant and the crop became at the same time less susceptible to *tirak* on saline subsoil and produced better quality of lint.

It may be of interest to observe that Trought (1930), the then Cotton Research Botanist, Lyallpur, published his observations on sowing date experiments on the basis of which he concluded that the crop sown in the first fortnight of June would have a greater rate of growth and increased flower and boll production than the crop sown in May. The reverse has, however, been found to be the case. This fact of decreased boll production can be deduced from his own experiments (Trought, Afzal and Iyer 1931). Their yield results, given below, showed that there was a decline in yields as the sowing date advanced.

Yield of 4F in lb. per acre for three sowing dates.

24th March.	1st May.	9th June.
156.2	134.7	86.3

It was evident from these results that there was no increased boll production as the sowings were delayed. The decrease in yields as the sowings were delayed must be due to a decrease in bearing as the spacing factor was not introduced. The relationship between sowing date and spacing has been very conclusively demonstrated by field experiments conducted in the course of this investigation. The sowing date experiments conducted by him were also not laid out from the point of view of amelioration of *tirak* as the causes of *tirak* were not known at that time.

(ii) AMELIORATION OF *Tirak* ON LIGHT SANDY SOILS DEFICIENT IN NITROGEN.

The ameliorative effect of late sowings on *tirak* caused by deficiency of nitrogen has already been pointed out in Chapter III. Adoption of late sowings on such light sandy lands aimed at economic utilization of available nitrogen in the soil, by reducing the plant size. It was shown that the concentration of nitrogen in leaves was maintained at a higher level at the fruiting time in the June-sown crop as compared with the leaves of the May-sown crop (Table VI in Chapter III). There was also great improvement in yield (Table VII). A factorial experiment designed to study the effect of sowing date, nitrogen, water supply and spacing on the vegetative and the reproductive characters of 4F Punjab-American cotton was conducted during 1939-40. The treatments comprised all combinations of : $\begin{Bmatrix} d1 \\ d2 \\ d3 \end{Bmatrix} \times \begin{Bmatrix} o \\ n \end{Bmatrix} \times \begin{Bmatrix} w1 \\ w2 \end{Bmatrix} \times \begin{Bmatrix} s1 \\ s2 \end{Bmatrix}$

where $d1=12/5/39$, $d2=2/6/39$, $d3=22/6/39$, o=no nitrogen, n=50 lb.N on 14/8/39, $w1$—normal watering, $w2$=heavy watering, $s1$=2ft.$\times 1\frac{1}{2}$ ft. and $s2=2\frac{1}{2}$ ft. $\times 2\frac{1}{2}$ft. spacings. The layout was a balanced arrangement with six twelve-plot blocks. High order interactions were partially confounded.

It was again found that the delay in the sowing of cotton by a given period did not cause an equal delay in the onset of the reproductive phase. The commencement of flowering was shifted forth by about six days with a delay in sowing by 20 days. The peak and the cessation of flowering were still less affected by the delay in sowing.

The results of the experiment have been fully discussed in a separate paper (Dastur and Mukhtar Singh, 1943) and only important and new features are summarised here. Records for height, node number, internodal length, dry weight, flowering, boll number, boll weight and yield were maintained.

TABLE XXXI (Expt. 10 in Appendix).

	Flowers per sq. yd.	Setting percentage.	Boll No. per sq. yd.	Boll weight in gm.	Yield in mds. p. a.
d_1 (12/5)	260.7	25.45	55.10	1.365	11.17
d_2 (2/6)	203.0	29.39	54.47	1.515	12.01
d_3 (22/6)	131.9	36.28	45.42	1.573	9.66
S. E.	$\pm$6.12	$\pm$0.75	$\pm$1.73	$\pm$0.039	$\pm$0.425
n	238.9	30.34	60.29	1.620	13.95
o	158.1	30.41	43.04	1.349	7.95
S.E..	$\pm$5.00	$\pm$0.62	$\pm$1.41	$\pm$0.032	$\pm$0.347

There was a progressive decrease in flower production with the delay in sowings but the effect of dates on the setting percentage was the reverse of that of flower production (Table XXXI). The percentage of flowers maturing into bolls increased steadily as the sowing date advanced. Thus the disadvantage of reduced flower production under late sowing was partly met by the increase in the setting percentage. Though the bolls were nearly equal in the first two sowings there was still a substantial decrease in their number in the third sowing. The effect of dates on boll weight was different from that in the case of flower production. The boll weight increased as the sowings were delayed. The second sowing, therefore, gave the maximum yield while the yield in the third sowing continued to be lower than the yields in the first two sowings on account of a decrease in bearing. The reason for the decrease in yield in the third sowing is explained below:

Nitrogen significantly increased the flowers, the bolls, the boll weights and the yields but the percentage of flowers set into bolls was unaffected (Table XXXI). There was a mean response on yields of six maunds of seed cotton per acre in the presence of nitrogen. The three sowings, however, did not behave alike in their response to nitrogen. The first two profited equally but the magnitude of increase in the third was much lower (Table XXXII).

TABLE XXXII.

	Boll Number.		
	*d*1 (12/5)	*d*2. (2/6)	*d*3. (22/6)
o ..	45.6	43 66	30.9
n	64.6	65.30	51 0
n-O .. (±3.44)	** +19.0	** +21.64	** +11.1
*s*1 .	56.2	54.9	53.2
*s*2 ..	54.0	54.0	37.6
*s*1-*s*2 . (±3.44	+2.2	+0.9	** +15.6

	Yield in maunds p. a.		
	*d*1. (12/5)	*d*2. (2/6)	*d*3. (22/6)
o ..	7.25	8.57	8.02
n ..	15.10	15.45	11.31
n-O .. (±0.85)	** +7.85	** +6.88	** +3.29
*s*1 ..	11.22	12.20	10.53
*s*2 ..	11.13	11.82	8.79
*s*1-*s*2 . (±0 85)	+0.09	+0.38	** +1.74

	Wt. of seed cotton per boll in gm.		
	*d*1. (12/5)	*d*2. (2/6)	*d*3. (22/6)
o ..	1.125	1.375	1.548
n ..	1.605	1.655	1.599
n-O .. (±0.079)	** +0.480	** +0.280	** +0.051
*s*1 ..	1.37	1.52	1.56
*s*2 ..	1.36	1.51	1.58
*s*1-*s*2 . (±.079)	+0.01	+0.01	—0 02

This was partly due to a greater increase in boll number under nitrogen in the first two sowings than in the third one. The fall in boll number in the third sowing as compared with the first two sowings was much lower in the absence of nitrogen than in its presence (Table XXXII).

The improvement in the boll weight through nitrogen fell off progressively as the sowings were delayed. This was because the boll weight increased with the delay in sowings only in the absence of nitrogen. The last sowing, therefore, was the least benefited by nitrogen application.

The differential responses to nitrogen in boll number and boll weight under different sowings were reflected in yields. The increase in yield in presence of nitrogen became less and less marked as the sowings were delayed (Table XXXII). The second sowing gave the maximum yield both in the presence and the absence of nitrogen while the third sowing was the next best in the absence of nitrogen and the first sowing in its presence.

No advantage accrued to the first two sowings in either the boll number or the yields by adopting close spacing while the third sowing definitely profited by close spacing (Table XXXII). Thus close spacing of plants was again found to be essential for the late sowings. The close spacing adopted in this experiment did not prove sufficiently close for the third sowing to bring up the level of its yield to that obtained in the first two sowings. The decrease in yield by wide spacing in third sowing was mainly due to a decrease in bearing as the boll weight was not affected.

Though the application of nitrogen was found to be a better measure than the June-sowings from the points of view of yields on light sandy soils, both were equally effective for ameliorating *tirak*. The level of yield was actually the higest in the third sowing without nitrogen under close spacing as shown below (Table XXXIII).

TABLE XXXIII.

Yield in maunds per acre.

	d_1 (12/5).	d_2 (2/6).	d_3 (22/6).
*s*1	7.19	7.68	8.17
*s*2	7.31	9.47	7.87
*s*1n	15.24	16.73	12.90
*s*2n	14.95	14.17	9.71

(*iii*) AMELIORATION OF *TIRAK* ON LIGHT SANDY SOILS WITH SALINE SUBSOIL.

There were fields in the Punjab where both the *tirak* promoting soil conditions were found to occur and it was necessary to study the performance of June-sowing or of the application of nitrogen on such fields. The effect on *tirak* and on yield can be seen from the following experiment conducted on such a field at the Lyllapur Agricultural Farm in the cotton season of 1939-40. There were two new features in the experiment. Firstly, *desi* cotton was included along with 4F and secondly the manure, superphosphate plus potash (PK), was tried as a treatment in order to confirm the previous findings that these two inorganic fertilizers had no effect on *tirak* or yields. To the main plots were allocated 8 combinations of three factors at two levels each ; two varieties (*v*1=4F, *v*2=desi), two sowing dates (*d*1=6th May, *d*2—10th June) and two levels of mixture of superphosphate+potash (control *vs* 50lb. P_2O_5+ 50lb. K_2O per acre applied on 4th August). The main plots were split for two levels of nitrogen (control vs. 25 lb. N applied on 4th August) and each subplot thus formed accommodated two spacing types (*s*1=2 ft., × 1½ ft., *s*2=2½ft. × 2½ ft.) It was thus a randomised block design with split plot arrangements. All the main effects on the basis of the statistical analysis of the data collected from this experiment are given in Table XXXIV.

TABLE XXXIV (Expt. 12 in the Appendix).

Main effects with differences and S.E.

Wt. of seed cotton per boll in gm.			Boll no. per sq. yard.			Yield of seed cotton in maunds per acre.		
n	=1.43	+0.07±0.046	*n*	=76.35	** +14.34±4.19	*n*	=13.26	** +3.32±0.32
o	=1.36		*o*	=61.01		*o*	=9.94	
*d*2	=1.61	** +0.43±0.062	*d*2	=72.22	** +8.09±3.12	*d*2	=13.61	** +4.02±0.54
*d*1	=1.18		*d*1	=64.13		*d*1	=9.59	
*v*2	=1.47	* +0.15±0.062	*v*2	=83.79	** +31.22±3.12	*v*2	=14.32	** +5.44±0.54
*v*1	=1.32		*v*1	=52.57		*v*1	=8.88	
*s*1	=1.38	—0.03±0.062	*s*1	=63.11	** —10.14±3.41	*s*1	=11.49	—0.22±0.22
*s*2	=1.41		*s*2	=73.25		*s*2	=11.71	

Nitrogen did not ameliorate *tirak* but affected the boll number favourably and thereby the yield. There was a substantial increase in yield by late sowing mainly through improvement in the opening of the bolls and partly through increased bearing. *Desi* outyielded significantly 4F Punjab-American because greater number of bolls of the former matured normally. In the case of 4F not only were the bolls fewer in number but they were also affected by *tirak* in the early-sown. It may be noted that the normal boll weight of *desi* cotton is about 1.5 gm. and that of 4F is 2.0 gm.

The relation between sowing date and spacing is given in Table XXXV below. The early-sown crop produced the same number of bolls at both the spacings provided, but a great increase in boll number occurred under the late-sown crop closely spaced. This effect appeared as a significant interaction on boll number and was simultaneously reflected on yield. Boll weight, however, improved by late sowing irrespective of the spacings.

TABLE XXXV.

Interaction : sowing date × spacing.

	Number of bolls per sq. yd.			Boll weight in gm.			Yield of seed cotton in maunds per acre.	
	*d*1.	*d*2.		*d*1.	*d*2.		*d*1.	*d*2.
*s*1 (close) ..	64.27	82.22	*s*1 ..	1.169	1.595	*s*1 ..	9.14	14.28
*s*2 (wide) ..	64.00	62.22	*s*2 ..	1.187	1.627	*s*2 ..	10.04	12.94
Diff : *s*2-*s*1 .. ±4.817	—0.27	** —20.00	Diff : *s*2-*s*1 ±0.042	+0.018	+0.032	Diff : *s*2-*s*1 ±0.370	* +0.90	** —1.34
D.S.= ** —9.86±3.406.			D.S.=+0.007±0.030.			D.S. = ** 1.12±0.261.		

* Denotes 5 per cent level of significance.
** Denotes 1 per cent level of significance.

The improvement in the opening of bolls, through late sowing, on light sandy soil with saline subsoil, was the same irrespective of the nitrogen level and the spacing adopted. But the yield response to delay in sowing varied in magnitude to the extent the boll number component was influenced, under the varying level of the other factors. Nitrogen did not raise the boll weight though some gain in yield resulted from increased bearing under nitrogen treatment.

As light sandy soils are also found to possess soils with saline or alkaline subsoils mixed up with non-saline normal subsoils, the application of sulphate of ammonia to these soils as a general measure for amelioration of *tirak* cannot be recommended. The late sowing on the other hand as a measure for amelioration of *tirak* and for maintaining or increasing the yield was found to be of general application.

(*iv*) AMELIORATION OF *Tirak* IN DIFFERENT VARIETIES OF COTTON.

The experiments discussed in the foregoing pages were conducted with 4F Punjab-American cotton variety only. It was, therefore, necessary to extend the studies by introducing in such experiments a number of *desi* and American varieties. Such a study would disclose not only the relative resistance of different American strains to *tirak*, if any, but also their suitability for adoption for late sowing.

Accordingly 18 varieties, 15 Americans and 3 *desis*, were included in the experiment. Out of the entire lot under trial, there were six commercial varieties, four Americans and two *desis*, while the rest were newly evolved promising strains of the Cotton Research Botanist, Lyallpur.

The layout conformed to randomised block design with split-plot arrangement. The entire area consisted of 6 blocks (320ft. × 119ft.) of 4 main plots each 80ft. × 119ft. Four sowing-date treatments were distributed at random to the main plots within each block. Two rows of 119 ft. length for each of the 18 strains were accommodated in each main plot. The position of varieties within each plot was perfectly random. Non-experimental belts were cut out on all sides at pickings to avoid border effect to the main-plot treatments.

Sowings were done on 8th May, 23rd May, 7th June, and 23rd June, in d_1, d_2, d_3 and d_4 plots respectively. At the time of thinning, the plants were spaced closer and closer as cotton was sown successively later. The spacings adopted for the different sowings were : d_1=2 ft. × 2 ft., d_2=2 ft. × $1\frac{1}{2}$ ft., d_3=2ft. × 1 ft. and d_4= 2ft. × 9 inch.

Yield records were maintained throughout the picking season. *Desi* varieties had to be picked every week and thus it was not convenient to record their boll weights in this experiment. Boll weight determinations from sampled plants were, therefore, confined to 15 American varieties of each sowing (Table XXXVI).

There was a progressive rise in the weight of seed cotton per boll with delay in sowing up to the third sowing beyond which there was little effect. Thus a well marked optimum towards the June-sowings was clearly brought out with respect to the opening of bolls. The magnitude of increase was sufficiently high. The sowing dates stood in the order d_3, d_4, d_2, d_1 according to merit and this order remained virtually the same in the different varieties taken individually. This accounted for the non-significant interaction between the two factors. Improvement in opening in all the varieties was brought about to the same extent by delay in sowing. The mean boll weight of the varieties showed significant variations among

TABLE XXXVI (Expt. 19 in the Appendix).

Results of the experiment at the Risalewala Seed Farm.

(1940-41).

	Average wt. of *kapas* per boll.					Mean yield in lb. per subplot (1/108 Acre.)				
	d1.	*d2.*	*d3.*	*d4.*	*Mean* ±0.06	*d1.*	*d2.*	*d3.*	*d4.*	*Mean* ±0.306
L.S.S.	1.37	1.56	2.11	2.08	1.78	3.63	5.03	6.66	6.80	5.53
4F	1.16	1.44	1.89	1.47	1.49	2.91	4.33	7.25	4.34	4.71
289F/43	1.19	1.74	2.18	1.68	1.70	2.98	4.20	5.11	4.61	4.23
289F/K25 ..	1.30	2.00	2.22	2.00	1.88	3.97	5.78	5.23	4.32	4.82
L.S.S. early ..	1.55	1.84	2.32	2.22	1.98	4.64	9.63	11.27	9.70	8.81
289F/124 ..	1.42	1.84	2.28	2.26	1.95	5.26	6.98	7.22	6.77	6.56
289F/126 ..	1.70	2.03	2.272	2.48	2.23	5.07	6.50	8.14	7.05	6.69
289F/127 ..	1.43	1.90	2.17	2.26	1.94	4.95	6.65	4.16	4.38	5.04
289F/144 ..	1.40	1.94	2.19	2.08	1.90	4.77	5.90	6.67	5.26	5.65
289F/155 ..	0.86	1.40	1.60	1.64	1.37	2.37	4.91	4.84	4.26	4.09
289F/156 ..	1.21	1.86	2.37	2.12	1.89	4.66	7.61	8.40	6.06	6.68
289F/157 ..	1.24	1.73	2.14	1.98	1.77	5.41	6.90	6.45	5.53	6.07
289F/158 ..	1.36	1.87	2.35	2.30	1.97	4.23	7.21	7.33	6.40	6.29
289F/159 ..	1.38	2.14	2.03	2.08	1.91	5.57	8.26	6.26	5.47	6.39
289F/186 ..	1.12	1.41	1.87	1.79	1.55	3.45	4.77	6.22	5.69	5.03
D.C. 17 ..	..	..	..	..	..	10.00	8.92	11.71	10.22	10.21
Mol. 39	..	..	..	..	..	12.09	10.74	15.14	13.32	12.82
Sang. 119 ..	..	..	..	..	..	9.24	11.01	12.03	10.58	10.71
Mean	1.31	1.78	2.16	2.03	..	5.29	6.96	7.78	6.71	..
			±0 87					±0.431		
Standard Error of the body of the table (interactions and varietal effects only).			±0.12					±0.612		

themselves. This indicated inherent varietal differences in the boll weight of the different strains. Boll weight is a composite measure of the all round development of seed and lint of a given variety but higher boll weights in certain varieties in comparison to others, did not necessarily imply a corresponding reduction in the percentage immaturity of seeds. Varieties having large and fuzzy seeds may suffer to the same extent by *tirak* and yet may possess markedly higher seed weights due to more of non-essential parts, as compared with non-fuzzy strains, under similar soil conditions.

The optimal value for yields was obtained in the third sowing after which there was a tendency for falling off in the effectiveness of further delay in sowing. This was attributable to a diminution in the boll number per unit area caused by a reduction in growth. Even then, the mean yields of the fourth sowing were higher than those of the first sowing and compared favourably with those obtained from the second sowing.

CHAPTER IX

REMEDIAL MEASURES FOR *TIRAK* (contd.)

The different effects of the two ameliorative measures, *viz.*, the application of nitrogen or of extra water from the mid-August on the opening and yields for the three types of soils, *viz.*, (1) light sandy, (2) light sandy with a saline or alkaline subsoil and (3) sandy loam with a saline subsoil were discussed in the previous Chapter. The late sowing was also tried as an alternative measure in the experiments discussed before and was found effective under all the three *tirak* promoting soil conditions. The quality of opening was invariably improved by delaying the date of planting the crop and there was an increase in yield to a greater or lesser degree in almost all cases. The importance of the late sowing as an ameliorative measure consisted in the fact that its effect was not restricted to any particular *tirak* promoting soil condition but was of general applicability.

The evidence in support of the above findings was collected from experiments conducted mainly at the Lyallpur Agricultural Farm with 4F Punjab-American cotton. It was, therefore, necessary to test the ameliorative effect of the late sowing on a wider basis by laying out experiments in the different cotton growing tracts in the Punjab using the commonly cultivated varieties of American cotton of each tract. It was also considered desirable to try out the other two ameliorative measures of the extra application of water or of nitrogen to confirm the findings obtained at Lyallpur. The inclusion of one *desi* variety (*G. Arboreum* variety *indicum*) in some of these experiments was also considered of interest. The extent to which the different varieties would respond to the three ameliorative measures, especially late sowing, could thus be determined.

The application of late sowing as a general measure for all cotton sowings in the Punjab was apprehended to be associated with certain practical difficulties. (1) If the cotton sowings are to be shifted from May to June it was feared that the date of the final irrigation to the cotton crop would have to be advanced by one month and such a practice would interfere with sowings of *rabi* crops. In the event of an earlier than usual canal closure this practice would prove very risky for wheat sowings. (2) It was apprehended that a late-sown crop would mature late and it could thus be exposed to damage from early frosts. (3) As the late-sown crop was more tender and succulent by the time the Jassid generally appeared, it was known to fall an easy prey to this pest in a year of heavy Jassid infestation.

It was necessary to obtain evidence to determine if these apprehensions were real and to provide satisfactory solution to those which were found to be so.

The soundness of an agricultural measure could best be determined by its trial under actual *zamindara* conditions. It was possible the results obtained under standard agricultural conditions on a scientifically managed farm might not come out 100% true on cultivators' farms. The experiments conducted on *zamindars'* farms were also of extra value in as much as they serve as centres for dissemination of new information gained.

(*i*) AMELIORATION OF *Tirak* ON ZAMINDARS' LANDS.

The sowings of American cottons in the Punjab generally began in the first week of May and normally they took three to four weeks to finish. Sowings on a

small area sometimes continued for the first ten days of June on account of the interference caused by early showers of rain or unexpected canal closures. 80% of the total crop was, however, sown in the month of May. If the June-sowings were to be recommended as a general practice it was necessary to determine the optimum period for cotton sowings so as to reduce the damage caused by *tirak* as much as possible without adversely affecting the yield caused by a decrease in bearing. Four sowing dates were, therefore, included to study the progressive change in the boll weight and yield with advancing sowing dates. The four sowing dates included in this study were, $d1$=2ndweek of May, $d2$=4th week of May, $d3$=2nd week of June and $d4$=4th week of June. In view of the established relations between sowing date and spacing, the spacings were progressively reduced as the sowings were delayed. They were $d1=2\frac{1}{2}$ft. × 2ft. ; $d2=2\frac{1}{2}$ ft. × $1\frac{1}{2}$ft, , $a3$= 2 ft. × 1 ft. and $d4$=2ft. × 9 in. The seed rate per acre and the spacings adopted in the past were the same irrespective of the sowings date. In view of the reduction in spacing as indicated above, the seed rates had to be progressively increased as the spacing was reduced in the late sowings.

In a series of experiments, all combinations of four sowings dates, two watering types (normal, heavy) and two levels of nitrogen (o, 33 lb. N per acre) were tried in 6 blocks of 8 plots each confounding completely with block differences the second order interactions. Three or four varieties were accommodated in each main plot. Differentiation in irrigation started after manuring in August. There were slight differences in the net plot size under four different sowings and statistical analysis was made by converting the plot yields to maunds (82.2 lb.) per acre. For determining the boll weight *i.e.*, for judging the improvement in opening or *tirak*, two sampling units were taken each comprising of adequate number of plants, selected at random in each subplot. The procedure afforded a valid estimate of the sampling error which was found to vary from 5% to 10%.

(*a*) Effect of Sowing Date, Nitrogen and Water on boll Weight.

The results of the weight of seed cotton per boll determined in two experiments laid out in two different districts are given in Table XXXVII.

TABLE XXXVII.

Average weight of seed cotton per boll in gm.

	Brucepur.						Khanewal.				
	$d1$ (8/5)	$d2$ (24/5).	$d3$ (8/6)	$d4$ (24/6).	Mean ±0.0285		$d1$ (13/5).	$d2$ (28/5).	$d3$ (14/6).	$d4$ (29/6).	Mean ±0.053
289F/43	1.29	1.52	1.78	1.67	1.57	289F/43	1.16	1.29	1.66	1.78	1.47
L.S.S. ..	1.42	1.58	1.90	1.68	1.65	K.25	1.09	1.45	2.00	2.12	1.66
Moll. 39	1.58	1.64	1.72	1.82	1.69	Moll. 39	1.74	1.79	1.78	1.75	1.77
Mean ±0. 72	1.43	1.58	1.80	1.73		Mean ±0.08	1.32	1.51	1.81	1.88	

Dates (Linear)=$1.\overset{**}{11}\pm0.32$ Dates (Linear)=$1.\overset{**}{96}\pm0.36$

The statistical analysis of the boll weight data revealed that the linear response to dates was highly significant in these experiments. It was evident from the results (Table XXXVII) that the highest boll weights were attained in the third and the fourth sowings. There was a progressive increase in the weight of seed cotton per boll with the delay in sowings in the American varieties while *desi* (Moll. 39) cotton generally maintained its boll weight in all experiments with the exception of the one at Brucepur. Sowing dates interacted with varieties whose mean boll weights also varied widely. The main effect of nitrogen and its interaction with varieties was not significant at the two places where the major portion of the experimental area was saline in the subsoil. The application of nitrogen had, however, significantly increased the boll weight at Convillepur where the soil was light sandy without salinity in the subsoil (Table XXXVIII).

TABLE XXXVIII.

Weight of seed cotton in gm. per boll—Convillepur Farm.

	*d*1 (8/5)	*d*2 (23/5)	*d*3 (7/6)	*d*4 (22/6).	Mean ± 0.043
o	1.76	2.28	2.30	2.31	2.16
n	2.15	2.28	2.44	2.30	2.29
Mean $\pm$0.043	1.96	2.28	2.37	2.30	..

The main effect of watering was found to be significant or suggestive wherever the soil was a sandy loam with a saline subsoil while it was insignificant at other places.

The results obtained in other experiments laid out in the same season or in the succeeding seasons were similar to those mentioned above. The June-sown crop always suffered less from *tirak* than the May-sown crop. The reduction in *tirak* depended on the intensity of *tirak* promoting conditions in the area where the experiment was laid out and the weather conditions that prevailed in that season. However, it was found in one case that when the crop came on a soil where either salinity or alkalinity was high from the soil surface the May-sown and June-sown crops showed the bad opening of bolls even though the trends in boll weights were in favour of the latter (Expt. 15 in Table XLVI). The improvement in boll weight though statistically significant, was very small in magnitude. It was also found that when weather conditions were favourable good opening may equally occur in the May-sown as well as the June-sown crop and there may be no differences in the weights of seed cotton per boll between the two sowings. This was also found to be the case in four experiments (Expt. Nos. 27—30 Table XLVI). In all the remaining experiments given in the Table XLVI at the end, the June-sown crop gave higher boll weights than the May-sown crop.

(b) Effect of Sowing Date, Nitrogen and Water on Yield.

The results of yields under different treatments were not identical with those discussed above for the opening of the bolls, as the yields depend not only on the boll weight but aslo on the boll number. Increase in the boll size may be associated with a decrease in the boll number, in which case quality gains at the expense of the quantity.

The results of yields obtained in these experiments showed two types of trend according to the districts in which they were laid out (Table XXXIX). In the central tracts of the Punjab, the yields under the two middle sowings, *i.e.*, *d*2 and *d*3, were found significantly superior to the yields under the two end sowings, *i.e.* *d*1 and *d*4 (Table XXXIXA). In the extreme western tracts, the yields under the last two sowings, *i.e.*, *d*3 and *d*4, were significantly superior to those of the first two sowings, *i.e.*, *d*1 and *d*2 (Table XXXIXB). In the central tract, the third sowing gave the maximum yield, while in the western tract the fourth sowing gave the maximum yield.

Table XXXIX.

Yield in maunds per acre.

	A. Brucepur (Expt. 20)						B. Khanewal (Expt. 21).				
	*d*1 (8/5)	*d*2 (24/5)	*d*3 (8/6)	*d*4 (24/6)	Mean ±0.52		*d*1 (13/5).	*d*2 (28/5).	*d*3 (14/6)	*d*4 (29/6).	Mean ±0.49
289F/43	8.78	9.72	10.69	.89	8.77	289F/43	6.95	7.26	9.26	12.26	8.93
L.S.S. .	9.63	12.52	15.93	10.34	12.10	K. 25 ..	9.06	10.85	11.54	11.72	10.79
Moll. 39	24.93	24.25	25.68	22.85	24.42	Moll. 39	21.71	22.20	22.66	25.44	23.00
Mean . ±1.026	14.44	15.49	17.43	13.02		Mean .. ±0.55	12.58	13.44	14.48	16.47	..

Dates (quadratic) = —5.46* ±2.05   Date (Linear) = 12.73** ±2.46

At Brucepur (Table XXXIXA) all varieties gave the highest yields under the third sowing. The yields increased rapidly with delay in sowing in L.S.S. As increase in 289F/43 through the late sowing proceeded slowly, the differences in yield between L.S.S. and 289F/43 widened as the sowing was delayed. Beyond the third sowing, decline in yield occurred but this decline was steeper in the case of 289F/43 and is to be attributed to the excessive curtailment in the period of vegetative growth of this early maturing variety. In such cases the spacing provided turned out to be inadequate on account of the limited growth made by the plant. As

the soil at Brucepur was sandy loam with saline subsoil, watering gave a significant increase in yield, varieties responding to watering in order of their yielding capacity, *viz.*, Moll. 39>L.S.S.>289F/43. Nitrogen did not give a significant increase in yield nor did it interact with any other factor because of the saline subsoil.

At Khanewal all the varieties gave highest yields in the fourth sowing (Table XXXIXB). The response to nitrogen application at Khanewal confined itself only to the *desi* variety which gave the maximum yield. Americans failed to respond on account of the salinity in the subsoil. Response to watering was recorded and it declined in magnitude with the delay in sowing.

Desi cotton generally gave the same yields, whether sown in May or June (Table XXXIX). *Desi* cottons did not suffer from *tirak* or the 'bad opening' of bolls. On soils with highly saline subsoils their growth was depressed and the bearing was reduced but the bolls opened normally with fully mature seeds (Table XXXVII). As these cottons are found to behave alike under different sowing dates they can be sown at any time in May or June. These are short stapled cottons and, therefore, are not of great commercial value.

289F/124 is a new strain evolved by the Cotton Research Botanist, Lyallpur and is now recommended for cultivation in the two districts of Montgomery and Multan. This new strain, was therefore, included in the experiments conducted in the two districts during the cotton season of 1941-42. This new strain, as can be seen from Table XL A & B, responded to late sowings in June both as regards yield and the opening of bolls.

TABLE XL.

	A. Yield in maunds per acre.					B. Weight of seed cotton per boll in gm.			
	MULTAN.					MONTGOMERY.			
	*d*1 (19/5).	*d*2 (6/6)	*d*3 (24/6).	Mean		*d*1 (15/5)	*d*2 (8/6).	*d*3 (24/6).	Mean
289F/43	11.65	12.45	13.49	12.53		1.81	2.03	2.09	1.98
289F/k25 ..	10.04	12.12	12.66	11.61		1.22	2.16	1.91	1.76
289F/124 ..	9.52	11.99	16.34	12.62		1.23	2.28	2.01	1.84
Mean	10.40	12.19	14.16		Mean . .	1.42	2.16	2.00	

S.E. (dates) = ±0.598 = 4.88% of mean. S.E. (dates) = ±0.596 = 3.2% of mean.

S.E. (varieties) = ±0.598 = 4.88% of mean. S.E. (variety) = ±0.596 = 3.2% of mean.

Before the late sowing could be put forth as a measure for general adoption, it was necessary to determine its behaviour on normal rich land where *tirak* did not normally occur. Very rich fields were, therefore, selected at Iqbalnagar (Montgomery district) and experiments were laid out to determine the yields under four sowing dates. The results showed that there was no decrease in yield as the sowing date advanced from 15th May to 30th June, provided the spacing was reduced as the sowings advanced. In fact the trends in yields, though insignificant, were in favour of the June-sowings (Expt. 25 in Table XLVIIA).

(c) Differential Behaviour of Varieties with Sowing Dates.

The differential behaviour of variety with sowing date was the outstanding feature of this investigation. It was found that 289F/43 variety in the central tracts (Lyallpur and Sargodha districts) and 289F/K25 in the Montgomery district did not do well when sown after 15th June on account of a marked decrease in their boll number under these conditions. 289F/K25 and 289F/124 behaved still worse under the June-sowings at Lyallpur. On the other hand L.S.S. in Lyallpur and Sargodha districts, 4F in Lyallpur district, 289F/43 in Montgomery and Multan districts and 289F/K25 and 289F/124 in Multan responded favourably to delay in sowing. These varieties are popular in their respective localities with the cotton growers and this renders the adoption of late sowing in general practice quite easy. The superiority of a variety adapted to a particular tract became better and better marked as sowing was delayed till the optimum date, which was usually found to be the second or the third week of June.

The cause for the better adaptability of certain varieties to late sowing is to be found in their ability to make sufficient growth so that the bearing capacity does not decline appreciably.

(d) Practical Application of Late Sowing.

To set up late sowing on a practical basis and to get an idea of the actual benefit derived from the adoption of this measure it was necessary to test it on a field scale. The British Cotton Growers' Association Farm, Khanewal, was the first big commercial farm that took the lead in this direction and offered co-operation to try out this measure extensively.

A simple but replicated sowing-date experiment with 289F/K25 variety was arranged in 1940 and was repeated in the two succeeding seasons. The experiment was repeated in different *chaks* (villages) in the three seasons. The experiment was so arranged that it covered all types of land and a generalized effect of the June-sowings could thus be obtained.

Each year, 12 strips of land, 2 acres each under uniform cropping, were selected. The 12 strips were distributed over 10 to 12 different squares (1 square=25 acres) of a *chak*. Each two acre strip was divided into four ½ acre plots to which assigned at random four sowing dates. Thus 12 replications of four sowing dates were provided. Six acres of crop came under each sowing date. The yield from each ½ acre plot was collected separately so that the results could be statistically analysed. The results are given below in Table XLI.

TABLE XLI

Chak No. 75. 1940-41

Sowing dates :	*d*1 (19th May)	*d*2 (4th June)	*d*3 (19th June)	*d*4 (5th July)	S. E.
Yield in maunds p. a. ..	12.62	14.48	16.10	14.92	0.62
		Chak No. 83. 1941-42			
Sowing dates :	(20th May)	(5th June)	(20th June)	(5th July)	
Yield in maunds p. a. ..	5.38	6.47	7.06	5.77	0.406
		Chak No. 81-82. 1942-43			
Sowing dates :	(22nd May)	(7th June)	(22nd June)	(15th July)	
Yield in maunds p. a. ..	9.49	14.87	15.48	8.57	0.912

There was remarkable similarity from year to year in the yield trend of the different sowings, in spite of the wide variations in the level of the yields, the character of the soils and the season. The June-sowings were consistently better than either the 1st or the 4th sowing and the highest yield was obtained from the crop sown about 20th June. In 1942-43 season the fourth sowing had to be resown on 15th July on account of rains. At this farm, the May-sowings of cottons have now been discontinued and the June-sowings are adopted with success.

(*ii*) LAST DATE OF IRRIGATION FOR LATE-SOWN CROPS.

It was pointed out before that the practical application of the late sowing as a general measure was apprehended to meet with certain difficulties. It was feared that a late-sown crop would become late, require a late irrigation in October and November and thus interfere with the sowings of the winter crops. In the event of a canal closure during October and November, competition for water was likely to prove very risky for wheat sowings.

Studies with regard to the last irrigation to cotton in relation to the date of its sowing were undertaken at three places during 1940-41. The treatment comprised of all combinations of four sowing dates and two varieties (289F/43; 289F/K25) in six blocks of four main plots each (D'''V confounded) with sub-plot arrangement for the late waterings as variables. Three watering types, *viz.*, *w*1=last watering on 30th September; *w*2=last watering on 15th October; and *w*3=last watering on 30th October, were allocated to the sub-plots to obtain precise information on the utility of late waterings for the early or the late sowings. The experiment was again repeated, at two of the three places, in 1941-42 which had a particularly hot and dry October.

Analysis of variance of the yield data individually for the different experiments revealed that the main effect of watering was significant in 3 out of 5 cases. It did not attain significance at two places (Iqbalnagar and Multan) in 1940-41 season due to high experimental errors. As the mean square for the error in these two experiments was of the same order, the results were pooled and the linear response to watering came out significant. Summarised results for the two seasons are given in the Table XLII.

TABLE XLII.

Effect of late watering on early and late sowings

(Yield in maunds p.a.)

	d1 (2nd week of May)	d2 (4th week of May)	d3 (2nd week of June)	d4 (4th week of June)	Mean	S.E.
			Iqbalnagar and Multan (1940-41)			
w1	11.83	11.44	12.75	14.19	12.55	
w2	11.16	14.04	12.85	14.30	13.08	0.389
w3	12.27	14.87	14.05	13.35	13.64	
			Iqbalnagar (1941-42)			
w1	18.06	20.14	19.19	18.31	18.92	
w2	19.33	22.01	21.43	20.36	20.78	0.460
w3	19.39	23.25	20.53	19.15	20.58	
			Mianchannun (1940-41)			
w1	11.84	13.27	12.49	10.21	11.95	
w2	10.55	12.48	13.06	10.22	11.58	0.318
w3	13.40	13.42	15.38	10.22	13.10	
			Mianchannun (1941-42)			
w1	9.54	10.51	12.19	10.38	10.66	
w2	9.55	10.85	12.89	11.95	11.31	0.242
w3	9.83	11.49	13.64	11.66	11.66	

One watering during October was necessary in all areas. The magnitude of the increase in yield was, however, small. Besides, irrigation after mid-October did not benefit the crop. In one case only, the difference between the two October waterings was significant.

The interaction dates × watering was found to be insignificant everywhere. There was, therefore, no differential behaviour of late watering with sowing dates and watering could be safely withheld after the middle of October from the late sowings as well as the early sowings. It may be, therefore, concluded that the need for any additional irrigation to late sowing, in particular, does not arise.

(*iii*) DANGER FROM JASSID TO LATE-SOWN CROPS.

The Jassid is a well known insect-pest of cotton and in the Punjab it appears in larger numbers during the months of August and September when the weather is generally warm and humid. The severity of Jassid attack varies from locality to locality and season to season depending upon the amount and the distribution of monsoon. Whereas the damage is of rare occurrence in Multan and is less frequent in Montgomery, the eastern tracts are exposed to danger periodically. The attack within a particular year extends as far as the favourable for the multiplication of the insect persists.

A crop may suffer more or less from Jassids in a particular year depending upon other factors, *i.e.*, variety, sowing time, the growth made by the plants, and incidental concurrence of rainfall in August and September with irrigations.

The damage from Jassids starts from the margins which become light yellow in appearance and assume characteristic curling on the lower side. There is also injury to the softer regions of the leaves in patches. Anthocyanins develop in the affected areas which ultimately die. It is also seen that the younger leaves are more susceptible to injury than the older ones as the former are more tender and more fleshy than the latter.

The June-sown crop is very succulent by the time Jassids appear. Consequently, it falls a prey to this insect more easily than the May-sown crop in a Jassid year. The danger to the June-sown crop would, therefore, be greater than to the May-sown crop.

The above observations were confirmed in the sowing-date experiments conducted in 1940-41 cotton season when owing to abnormal rains in the month of August the pest appeared in large numbers in September and attacked the June-sowings of 289F/K25 (a susceptible variety) with devastating results. It was also noticed that, as a rule, the Jassid attack was greater in the plots that were manured with sulphate of ammonia than in the unmanured ones in all sowings. Careful observation of the plots under the June-sowings in several experiments, however showed one new feature, hitherto undiscovered. The June-sown crop that was closely planted and which had covered the soil before Jassids appeared were less attacked than those which had not covered the soil for one reason or other. Wide spacing or salinity near the soil surface or very sandy character of the soil are responsible for the inability of the late-sown crop to cover the ground. It was thus concluded that the June-sown crop should cover the ground before the appearance of the insect to escape danger from its attack.

As the above-mentioned observation pertaining to the influence of spacing on the incidence of jassid attack was of great agronomic value, it was tested out experimentally in the succeeding cotton season (1941-42). A simple experiment comprising four spacings as variables was laid out at Lyallpur in 1941-42. The four spacings were, $s1=1$ft. $\times$ 1ft., $s2=1\frac{1}{2}$ft. $\times$ $1\frac{1}{2}$ft., $s3=2$ ft. $\times$ 2 ft. and $s4\times 2\frac{1}{2}$ ft. $\times$ $2\frac{1}{2}$ ft. Six replicates were kept. The crop was sown on 19th June. The soil in this field was more alkaline than normal at the surface at some places, where the growth of the plants was known to remain stunted. Thus the damage caused by Jassids on closely and widely spaced plants and on those that remained stunted on account of unfavourable soil conditions could be simultaneously determined.

Jassids appeared in August and observations showed that the Jassid attack was less on closely-spaced plants which had covered the soil as compared with that on widely-spaced plants where ground was not covered. Similarly the damage to plants that had remained stunted due to surface salinity or alkalinity was also greater than where the growth was normal. The damage under the $s1$ and $s2$ spacings was definitely less than the damage in the $s3$ and $s4$. There was also a steady decline in the yield and boll weight as the spacings became wider and wider (Table XLIII). The decrease in yield with wider spacings is not to be attributed in full to greater incidence of Jassid attack under these conditions but is in good part the direct outcome of a reduction in the boll number brought about by a decrease in the plant number.

TABLE XLIII

	s1 (1ft.× 1ft.)	s2 (1½ft.× 1½ft.)	s3 (2ft.× 2ft.)	s4 (2½ft.× 2½ft.)	S. E.	Remarks
Yield in maunds p. a.	16.79	14.15	11.45	8.30	±0.84	Previous crop-cotton.
Wt. of seed cotton per boll in gm. ..	2.55	2.33	2.04	1.91	±0.101	Sowing date—19th June.

The above experiment was repeated in 1942-43 which too happened to be a year of heavy Jassid infestation. In addition to 4F, a susceptible variety, 289F/124, was included in the experiment. The previous observations regarding the relation of spacing with Jassid attack were confirmed and the yield and boll weight results were similar to those of the preceding season (Table XLIV).

TABLE XLIV

Effect of spacing on yield and boll weight of June-sowing. Lyallpur 1942-43

Variety		s1 (1ft.+ 1ft.)	s2 (1½ft.× 1½ft.)	s3 (2ft.× 2ft.)	s4 (2½ft.× 2½ft.)	S. E.	Remarks
Yield in maunds p. a.	4F	16.34	14.85	8.84	8.07	±0.698	Previous crop-cotton.
	289F/124	13.79	8.85	6.03	3.97	±0.698	
Boll wt. in gm.	4F	2.58	2.38	1.90	2.13	±0.149	sowing date—21-22 June.
	289F/124	2.89	2.72	2.50	2.16	±0.149	

In previous years when the fields spoiled by untimely rain before germination or damaged by insects or hailstorm, had to be resown in June, they were sown at 3 ft. between the rows. Such fields were later badly attacked in a Jassid year as the crop was not able to cover the soil by the time the insect appeared and consequently the damage by Jassids was very great. It has already been stressed that with each advancing week in June closer and closer spacings were necessary to make up for decreased bearing in the later sowings. In the light of the above, the damage to Jassids would also be automatically lessened as the closely spaced crop sown in June would cover the soil by the time Jassids appeared.

(*iv*) DANGER OF FROST TO LATE-SOWN CROPS.

The seed cotton collected at each picking under each sowing date, in the several experiments, was expressed as percentage of the respective aggregate yield to ascertain how late the crop arrival became when the sowings were done in June. The results of one experiment are given in Table XLV.

TABLE XLV.

Arrival of the crop expressed as percentage of the total.

	289F/43				289F/K25			
	% of crop arrival up to				% of crop arrival up to			
	15-20 Oct.	15-20 Nov.	15-20 Dec.	10th Jan.	15-20 Oct.	15-20 Nov.	15-20 Dec.	10th Jan.
d1 (13/5).. ..	41.0	77.5	90.5	100	33.7	80.2	92.7	100
d2 (28/5).. ..	29.0	66.5	92.0	100	21.6	70.6	91.0	100
d3 (12/6).. ..	..	67.5	90.5	100	..	60.5	90.8	100
d4 (29/6).. ..	..	60.0	89.0	100	..	44.6	86.6	100

The crops finished at the same time, whether they were sown in May or June. Nearly 90% of the crop of 289F/43 and 289F/K25 was picked by the third week of December under all sowings. L.S.S. is known to be a late variety but there again, the crop arrival was of the same order in the different sowings at Lyallpur. Thus by late sowings the crop does not mature late. This finding was again confirmed by the results of experiments in other seasons. In the cotton growing tracts of the Punjab frosts generally occur at Christmas and thus there is no special danger to late sowing in comparison to early sowing.

The damage from an early frost to the crops sown on different dates can only be assessed when very early frost does occur. In such years the cotton crop may suffer to an extent depending upon the degree of the delay in the crop which is controlled by many factors like variety, season, insect attack (the crop becomes late in a White Fly year), nitrogen level and water supply operating singly or in combination. To these may be added the sowing date as one of the factors. It must, however, be remembered that early frosts are of a rare occurrence. Of recent years, the winter of the year 1932 was the only instance when frost was recorded as early as November.

(*v*) PERFORMANCE OF JUNE-SOWINGS ON RICE RECLAIMED LANDS.

There are large areas of land in the Punjab which are impregnated with sodium salts (*kalar*). Attempts are made to reclaim such lands and bring them into cultivation. The Irrigation Research Department of the Punjab is reclaiming such land by planting rice in summer and by giving a large number of irrigations to it. Thus they are able to mature a crop of rice and at the same time wash the salts down to the deeper layers of the soil. The lands reclaimed by rice are expected to be leached of nitrates. Rice on such soils is always followed by gram, a leguminous crop, in the succeeding winter season in order to restore the nitrogen of the soil. The gram crop is succeeded by cotton in the following summer. It was therefore necessary to study the behaviour of the June-sowings on such reclaimed lands before a final recommendation for the June-sowings as a general practice could be

made. It was also necessary to determine if the gram crop adequately replenished the nitrogen supply of the soil or an additional application of nitrogen in the form of sulphate of ammonia was necessary. Four acres of such reclaimed area were acquired for the experiment at Mianchannun (S. B. Ujjal Singh's Farm) and an experiment comprising a study of all combinations of three sowing dates, three varieties (289F/43, 289F/K25 and 289F/124) and three nitrogen treatments (o, nitrogen at sowing and nitrogen at flowering @ 50 lb. N per acre in the form of sulphate of ammonia) was laid out. The results of yield and boll weight are given in the following Table XLV A.

TABLE XLV A.

	Yield in mds. per acre.			
	19/5 (*d*1)	6/6 (*d*2)	26/6 (*d*3)	Mean [±0.464]
Control ..	7.96	10.28	8.21	8.82
Amm. Sulph. at sowing ..	9.28	12.06	9.85	10.40
Amm. Sulph. at flowering ..	11.98	12.33	11.62	11.98
Mean (±0.464)	9.74	11.56	9.89	

S.E. (Dates or Nit.) = 4.47% of mean.

	Wt. of seed cotton per boll in gm.			
	19/5 (*d*1)	6/6 (*d*2)	26/6 (*d*3)	Mean [±0.053]
Control ..	1.91	2.90	3.05	2.62
Amm. Sulph. at sowing ..	2.22	2.83	3.20	2.74
Amm. Sulph. at flowering ..	2.48	3.17	3.15	2.93
Mean (±0.053)	2.20	2.97	3.13	

S.E. (Dates or Nit.) = 1.91% of mean.

The control plots of the May-sown crop showed symptoms of nitrogen deficiency *i.e.*, premature yellowing and shedding of leaves. The opening of bolls progressively improved as the sowings were delayed. There was also improvement in opening by the application of nitrogen. Thus symptoms of *tirak* due to nitrogen deficiency appeared on such rice reclaimed lands even though a gram crop was grown after rice.

Both the early and late applications of nitrogen significantly increased the yields but the increase in yield under the late application was greater than that under the early application. Nitrogen significantly increased the yields in all the three sowings. The magnitude of increase was slightly greater in the May-sown than in the June-sown crop. The results indicated that the rice reclaimed areas would need additional application of nitrogen and that the inclusion of gram in the rotation did not sufficiently replenish the nitrogen level for the full maturation of the cotton crop.

The middle sowing gave the maximum yield while there was no difference in yields between the 1st and the 3rd sowing even though the best opening occurred in the third sowing.

(*vi*) SUMMARY OF ALL SOWING-DATE EXPERIMENTS CONDUCTED FROM 1938 TO 1942.

A large number of field trials were made during the period 1937—1942 to study the effect of various agronomic factors on the yield and opening of cotton. The descriptive details as to the year, station, nature of soil, previous crop, factors studied and their levels, number of replicates and the plot size for all such experiments are embodied in the Appendix at the end. Out of them 41 experiments contained sowing date as a distinct factor and the number of sowing dates kept varied from two to four.

Effect of sowing date on boll weight.

The results of the boll weight determinations made in 27 sowing-date experiments are presented in Table XLVI giving the weight of seed cotton per boll in gm. under each sowing date in each experiment. The mean response to sowing date was significant in 22 cases out of 27, indicating that the late-sown crops suffered less from *tirak* than the early sown crops. Where three or four sowing dates were adopted, the linear response to sowing date indicated an increase in the seed maturity as sowings were progressively delayed. In some cases quadratic response was also significant showing that the middle sowings produced the best bolls. The first sowings, however, in every case gave the lowest boll weight as they suffered most from *tirak*. In spite of the presence of surface salinity and infertility of soil under Expt. 15, which caused 'bad opening' of bolls in all the three sowings, the trend was in favour of later sowings. There was no difference in boll weight under different sowings in Expts. 27, 28, 29 and 30 as the crop did not suffer from *tirak* and the boll weight under each sowing was more than 2 gm. Only in Expt. 50 was the order of boll weights reversed in favour of the early sowing because the later sowings were heavily damaged by Jassids and the last sowing was twice encrusted before germination.

Effect of sowing date on yield.

The effects of sowing date on yield have been summarised in Table XLVII A The mean response to sowing date averaged over all levels of the remaining factors came out to be linear in 15 experiments (Nos. 5, 6, 7, 12, 15, 16, 19, 21, 25s, al, 32, 33, 36, 39, & 45), indicating that the yields increased as the sowing date advanced from the middle of May to the end of June.

Quadratic response to sowing dates was significant in 18 experiments (Nos. 8, 10, 14, 18, 20, 22, 23, 24, 26, 30, 34, 35, 40, 41, 46, 47, 49, & 54), placing the optimum sowing period round the one or two central sowings according to the number of sowing dates, *viz.*, 3 or 4 included in the experiments. The deflection in the linear trends was brought about by two main causes; (1) the inclusion of 289F/K25 and 289F/43 in the experiments in those districts where they possess an earlier optimum as already demonstrated in the text. The interaction between dates and variety (Table XLVII B) was significant in a majority of these cases (Expt. Nos. 18, 20, 22, 24, 30, 34 & 35), supporting the above conclusion; (2) the introduction of nitrogen, watering and spacing treatments which interacted more favourably with the early sowings and tended to raise their mean yields to the level of the mean yields of the late sowings. The interaction effects (Table XLVII B) in Expt.Nos. 8, 10, 22, 44 and 46 were so strong that the superiority of late sowings in the absence of watering or nitrogen or spacing was completely neutralized. In Expt. No. 41 the 4th sowing had to be resown on 15th July on account of early rains. This date proved to be too late.

In the remaining cases (Expt.) Nos. 11, 13, 17, 23, 27, 28, 29, 44) no significant differences in yields were recorded for different sowings. The reasons for the absence of response to late sowings were: (1) inadequate spacing adopted for the late sowings as it was not possible to fix correct spacing in the early stages of the investigation, (2) absence of *tirak* in some experiments (Expt. Nos. 27, 28, 29), so both sowings behaved alike, and (3) high standard error in the experiment Nos. 23 and 24 on account of very patchy stand over a large experimental area. If the yields of these two experiments are studied in Table XLVII A, it will be seen

that the middle sowings were the best and the quadratic response to dates would have come out significant, had it not been for high standard error. There was also an indication of an interaction between sowing date and nitrogen. In Expt. 50, the third sowing done on 2nd July was twice encrusted with rain and germination was adversely affected, giving rise to a patchy stand. In addition the Jassid severely damaged the two late sowings. For Lyallpur district, late June-sowings are not recommended.

The two schedules A and B mentioned below to give practical guidance to *zamindars* for the optimum sowing time for each variety of cotton in each district and the seed rate and spacing to be adopted for each week in the sowing period have been prepared in light of the results of experiments summarised above.

TABLE XLVI.

Mean boll weight in gm. under different sowing dates.

Serial No.	May.				June.				July.	S. E.
	1st week	2nd week	3rd week	4th week	1st week	2nd week	3rd week	4th week	1st week.	
5	1.88						2.30			0.044
6	0.59				0.73					0.038
8		1.28					1.47			0.064
10		1.37			1.52			1.57		0.039
12	1.18					1.61				0.044
13			1.64				1.84			0.033
14		1.68		1.71		1.86				0.019
15	0.69			0.78					0.85	
18		1.96		2.28		2.87		2.30		0.043
19		1.31		1.78		2.16		2.03		0.087
20		1.43		1.58		1.80		1.73		0.072
21		1.32		1.51		1.81		1.88		0.080
24		1.36		1.86		2.23		1.78		0.13
27			2.70					2.75		0.077
28			2.06			2.12				0.053
29			2.82			2.70				0.091
30		2.88			2.92		2.84			0.039
31		2.27					2.81			0.129
32				1.09				1.29		0.026
33			1.84		1.87		2.25		2.45	0.216
35			1.42			2.16		2.00		0.060
45				2.33				3.25		0.117
46		3.01					3.79			0.073
47			2.20		2.97			3.13		0.053
49	2.08			2.43			2.38			0.083
50			2.21			2.10			1.52	0.051
54			2.36		2.97			3.20		0.037

Table XLVII A.

Mean yield in maunds p.a. under different sowing dates.

Serial No.	May.				June.				July.	S. E.
	1st week.	2nd week.	3rd week.	4th week.	1st week.	2nd week.	3rd week.	4th week.	1st & 2nd week.	
5	15.09						27.81			0.503
6	4.82			6.80						0 377
7	7.66					10.09				0.364
8		13.43					13.82			1.060
10		11.18			12.01			9.67		0.425
11			11.26				12 63			0.699
12	9.59					13.61				0 378
13			18.31				19.41			0 830
14		10.20		11.04		10.75				0.188
15	1.13			1.51					2.20	0.196
16		5.90					9.13			0.475
17	1.14					1.60				0.255
18		14.81		17.74		16.04		13.14		0.570
19		5.29		6 96		7.78		6.71		0 431
20		14.44		15.49		17.43		13.02		1.026
21		12.58		13.44		14 48		16.47		0.550
22		9.52		10.61		10.91		7.05		0.532
23		9.06		12 62		11.18		7.08		0 617
24		11.92		13.05		13 68		10.21		1 113
25		14.12		14.82		15.71		16.06		1.040
26		9.39		12.10		10 73		11.85		0.672
27			18.16					18.65		
28			14.24			14.08				0.245
30		20.99			21.25		19.04			0 330
31		8.65					11.24			0.310
32				5.67				8.31		0.490
33			9.64		10.95		12.91		11.33	0 920
34			18.93		21.80		20.38	19.27		0.880
35			9.01			11.93		9.67		0.420
36			10.40		12.19			14.16		0.598
39			12.62		14.48		16.10		14.92	0.620
40			5.38		6.47		7.06		5.77	0.406
41			9.5		14 87		15.48		8.57	0.912
44		10.70			12.56		9.22			1.095
45				14.56				21.64		0.830
46		13.03					13.98			0.444
47			9.74		11.56			9.89		0.464
49	14.75			17.25			14.16			1.027
50			14.90			12.15			5.06	0.357
54			15.70		19.06			16.82		0.409

TABLE XLVII B.

Tables showing significant first order interactions.

Dates × varieties.

Maunds per acre.

	Expt. 18			
	d1 (8/5)	d2 (23/5)	d3 (7/6)	d4 (22/6)
289F/43.. ..	12.09	16.11	16.40	12.43
289F/k25 ..	10.23	12.49	10.87	4.76
Moll. 39	22.10	24.61	20.85	22.22

Maunds per acre.

	Expt. 20			
	d1 (8/5)	d2 (24/5)	d3 (8/6)	d4 (24/6)
289F/43 ..	8.78	9.72	10.69	5.89
L.S. S. ..	9.63	12.52	15.93	10.34
Moll. 39 ..	24.93	24.25	25.68	22.85

	Expt. 22			
	d1 (15/5)	d2 (30/5)	d3 (15/6)	d4 (30/6)
289F/43.. ..	5.37	5.87	5.81	2.56
L. S. S.	8.53	10.17	12.64	5.19
4F	7.00	8.30	8.79	3.19
Moll. 39	17.79	18.09	16.41	17.27

	Expt. 24			
	d1 (15/5)	d2 (30/5)	d3 (14/6)	d4 (29/6)
289F/43 ..	10.85	11.57	14.62	11.60
289F/k25 ..	13.01	14.54	12.67	8.84

	Expt. 30		
	d1 (13/5)	d2 (1/6)	d3 (20/6)
289F/43.. ..	18.67	18.99	16.81
L. S. S.	22.84	23.72	22.91
4F	21.46	21.03	17.41

	Expt. 34			
	d1 (17/5)	d2 (5/6)	d3 (17/6)	d4 (30/6)
289F/43	16.92	19.62	21.81	20.87
289F/k25 ..	20.93	23.98	18.96	17.67

	Expt. 35		
	d1 (15/5)	d2 (8/6)	d3 (24/6)
289F/43	10.11	10.98	9.75
289F/k25 ..	7.73	10.11	7.87
289F/124 ..	9.19	14.71	11.39

Dates × nitrogen.

	Expt. 22			
	d1 (15/5)	d2 (30/5)	d3 (15/6)	d4 (30/6)
o	8.09	8.68	10.21	7.09
n	10.96	12.53	11.62	7.01

	Expt. 10		
	d1 (12/5)	d2 (2/6)	d3 (22/6)
o	7.25	8.57	8.02
n	15.10	15.45	11.31

	Expt. 46	
	d1 (13/5)	d2 (20/6)
o	10.78	12.90
n	15.28	15.06

Dates × watering.

	Expt. 8	
	d1 (14/5)	d2 (21/6)
Normal	10.09	13.70
Heavy	16.77	13.94

(vii) Practical Recommendations for Adoption of Late Sowing as a General Practice.

The investigation has brought to light the importance of spacing in relation to late sowings. The relationship between spacing and sowing date has been fully discussed in the scientific papers published on this investigation (Dastur and Mukhtar Singh 1942 and Dastur and Mukhtar Singh and Sucha Singh 1944). This finding is in accord with the experience of workers on cotton in the Sudan (Gregory *et al*, 1932; Lambert and Crowther, 1935). The following schedule 'A' gives an idea of the changing seed rates and spacings with advancing weeks in June and has been specially prepared from a practical point of view to suit the Punjab conditions.

Schedule 'A'.

Date of sowing.	Seed rate to be used per acre.	Distance to be kept between rows.	Distance to be kept between plants.
25th May —31st May	7—9 seers.*	2½ feet.	1½ feet.
1st June—7th June	8—10 „	2½ „	1¼ „
8th June—15th June	10—12 „	2 „	1¼ „
16th June—23rd June	12—14 „	2 „	1 „
24th June—30th June	14—16 „	1½ „	9 inches.

* 1 seer=2 lbs.

It must be borne in mind that the spacing recommended for each week in the above schedule is an approximation and it may be found too close on rich soils or too wide on poor soils.

A cultivator is unable to sow all his cotton on a single day. Sowings have got to be distributed over two, three or even four weeks depending upon the availability of water, sowing facilities and method of sowing. The optimum sowing period rather than sowing date is to be decided upon. Thus sowings will have to extend on either side of the optimum date, as revealed by experiments, and the varieties chosen for each tract should be appropriate as the varieties vary in their suitability for late sowing.

The range of sowing period for different localities was found to be different even if the right variety was used in the right place. As the primary reason for recommending late sowing is to maintain water balance of the crop under conditions of physiological or physical drought or both, it is natural that late sowing is essential in drier parts, *viz.*, Multan and parts of Montgomery. In these parts the sowings can extend as far as the end of June, as the long spell of hot and dry weather proves disastrous for the May-sowings. In parts where comparatively wet summers are more frequent, *e.g.*, Sarghoda and Sheikhupura, delay beyond the middle of June in years of heavy rainfalls would expose the crop to danger of Jassids. But at the same time the early sowings would be exposed to danger of *tirak* under certain soil conditions in dry years. At such places the rule should be to start late, sow quick and plant thick. For localities like Lyallpur, part of Montgomery and Jhang which occupy an intermediary position as regards the distribution of rainfall the sowing should be completed before 20th June. The schedule 'B' gives in a concise form the idea of the sowing periods based on the above conclusions.

SCHEDULE 'B'.

District.	Best sowing period.	Variety.
Sarghoda, Sheikhupura ..	25th May—15th June ..	L.S.S.
Lyallpur, Jhang and wet parts of Montgomery ..	25th May—20th June ..	L.S.S. and 4F; 289F/43, if sown, should be completed before 15th June.
Montgomery	25th May—25th June ..	289F/K25 and 289F/43. K25 should not be sown after the middle of June.
Multan	1st June—25th June ..	289F/124.

As a general practice, it is advisable to concentrate sowings in the first fortnight of the sowing period indicated in the Schedule 'B' on light sandy soils or on soils of low fertility where growth is expected to be unduly depressed if sown very late. The remaining sowing period can best be utilised for sowings on sandy loam fields where the growth of very late sown crops is sufficiently rapid to cover the soil.

(viii) Appendix giving Details of All Experiments from 1937-1942.

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
1	Lyallpur Agricultural Farm.	1937	Light sandy.	Fallow.	Farmyard manure.	Control; 5 tons p.a. in main plots.	3 blocks. 12 mainplots	(a) 27 × 80	1/20.1
					Watering ..	Normal; Heavy	96 subplots.	(b) 21 × 43.2	1/48
					Nitrogen ..	Control; 22 lb. N. at sowing + 28 lbs. N. p.a. at flowering.			
					Potash	Control; 48lb. K_2O p.a. at sowing.			
					Phosphorus ..	Control; 120 lb. P_2O5 p.a. at sowing.			
2	,,	,,	Light sandy with saline subsoil.	Oil seeds.	Qualities of nitrogen.	(a) Control, (b) sulphate of ammonia, (c) potassium nitrate, (d) ammonium phosphate (niciphos) (e) calcium nitrate @ 50 lb. N. p.a. at sowing.	4 blocks ..	(a) 20 × 63.5 (b) 15 × 48.4	1/34.3 1/60
3	,,	1938	,,	Cotton.	Nitrogenous manures.	(a) Control, (b) 25 lb. N. at sowing +50 lb. N. at flowering, (c) 20 tons F.Y.M. at sowing, (d) 20 tons berseem p.a. at sowing.	2 replicates. 8 blocks (by confounding).	(a) 15 × 60.5 (b) 10 × 48.4	1/48 1/90
					Irrigations Potash.	Control; two presowing irrigations (a) control, (b) 120 lb. K_2O (c) 240 lb. K_2O (d) 360 lb. K_2O. p.a. at sowing.	64 plots.		
4	,,	,,	Light sandy	Oil seeds.	Nitrogen ..	Control; 50 lb. N. at sowing; 50 lb. N at flowering; 50 lb. N. at sowing+50 lb. N. at flowering p.a.	2 replicates. 8 rows. 8 columns. 64 plots.	(a) 33 × 60.5	1/21.8
					Potash	Control; 200 lb. K_2O p.a. at sowing.	Quasi-Latin square.	(b) 15 × 48.4	1/60
					Phosphorus ..	Control; 100 lb. P_2O_5 p.a. at sowing.			
					Watering ..	Normal; Heavy.			
5	,,	,,	Sandy loam with saline subsoil.	Fallow.	Sowing date ..	5th May; 16th June in main plots.	4 blocks. 8 mainplots	(a) 16.5 × 33	1/80
					Miscellaneous treatments.	(a) Control, (b) 1000 lb. Gypsum p.a before sowing and flooding, (c) Flooding before sowing, (d) 50 lb. N. + 100 lb. P_2O5 at sowing p.a., (e) 10 tons F.Y.M. p.a. (f) (b)+(d) together.	48 subplots.	(b) 12 × 23.7	1/153

(viii) APPENDIX GIVING DETAILS OF ALL EXPERIMENTS FROM 1937-1942—(contd.)

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Leve lof each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
6	Lyallpur Agricultural Farm.	1939	Light sandy soil with saline subsoil.	Oil seeds.	Miscellaneous treatments.	(a) Control, (b) 1500 lb. gypsum p.a. before sowing, (c) 40 tons silt p.a. before sowing, (d) 10 tons of berseem p.a. before sowing, (e) 50 lb. N.+100 lb. P2O5 in two doses, half at sowing and half at flowering, (f) (d) +(e) together.	6 blocks 36 main plots 72 subplots.	(a 13×30 (b) 8×22.5	1/111 1/242
					Sowing date ..	1st May ; 1st June ; in subplots.			
					Varieties ..	4F ; Mollisoni 39.	4 blocks 16 plots.	(a) 16.5×33	1/80
7	„	„	Sandy loam with saline subsoil.	Cotton.	Sowing date ..	4th May ; 15th June.		(b) 12×22	1/165
8	„	„	„	Fallow.	Nitrogen .. Spacing .. .. Watering .. Sowing date ..	Control ; 50 lb. N. at Sowing p.a. s1=2ft. × 1½ft., s2=2½ft.×2½ft. Normal ; Heavy. 14th May ; 21st June	4 replicates 8 columns 8 rows. 64 plots Quasi-Latin square.	(a) 12×32 (b) 8×22.5 (c) 7.5×22.5	1/113 s1=1/242 s2=1/258
9	„	„	„	Cotton.	Miscellaneous treatments.	(a) Control, (b) 1500 lb. gypsum before sowing, (c) 40 tons silt at sowing, (d) 10 tons berseem before sowing, (e) 50 lb. N+100 lb. P2O5 in two doses, half at sowing and half at flowering, (f) (d)+(e) together.	6 blocks. 36 plots.	(a) 16.5×33 (b) 12×22	1/80 1/165
10	„	„	Light sandy	Oil seeds.	Nitrogen .. Spacing	Control ; 50 lb. N. p.a. at flowering s1=2ft×1½ft., s2=2½ft.×2½ft.	3 replicates. 6 blocks 72 plots. Balanced arrangement.	(a)32.5×60.5 (b) 12.5×47.5	1/22.1
					Watering ..	Normal ; Heavy watering from mid-August.		(c) 14×48	s2=1/73.4 s1=1/64.8
					Sowing date ..	12th May ; 2nd June ; 22nd June.			
11	Abdul Hakim	„	Light sandy with saline subsoil.	Cotton.	Nitrogen ..	Control ; 33 lb. N p.a. at flowering	4 blocks 32 plots 64 subplots.	(a) 18×95	1/25.4
					Variety	4F ; Mollisoni 39.			
					Watering ..	Normal; heavy watering from mid-August.		(b) 18×95	1/25.4
					Sowing date ..	18th May : 18th June.			

(viii) Appendix Giving Details of All Experiments from 1937-1942—(*contd.*)

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
12	Lyallpur Agricultural Farm.	1939	Light sandy with alkaline subsoil.	Oil seeds.	Nitrogen ..	Control; 25 lb. N. at flowering p.a.	3 blocks. 24 main plots 16 transverse plots. 16 longitudinal plots 96 subplots.	(a) 14×30	1/103.7
					Potash+ Phosphorus	Control; 50 lb. K_2O + 50 lb. P_2O5 p.a. at flowering.		(b) 10×21	1/207.5
					Variety ..	4F; Mollisoni 39.			
					Spacing	2ft. × 1½ft., 2½ft. × 2½ft.			
					Sowing date ..	6th May; 10th June			
13	"	1940	Sandy loam with saline subsoil.	Cotton.	Cultivation ..	Normal; Heavy, in longitudinal plots.	6 blocks. 24 longitudinal plots. 48 arrays. 48 main plots. 96 subplots.	(a) 14×69	1/45.1
					Variety	4F; Mollisoni 39.		(b) 10×54.5	1/80
					Watering ..	Normal; Heavy from mid-August in main plots.			
					Sowing date ..	18th May; 20th June; in arrays.			
14	"	"	Light sandy with alkali patches.	Oil seeds.	Nitrogen ..	Control; 16 lb. N., 32 lb. N., 48 lb. N. p.a. in main plots.	3 replicates. 6 blocks. 24 longitudinal main plots. 72 longitudinal Subplots. 96 transverse plots. 288 subplots.	(a) 18×42	1/57.6
					Time of application.	Early (at sowing); Late (at flowering) in main plots.		(b) 14×31.1	1/100
					Variety	289F/43; 4F; L.S.S.; Mollisoni 39			
					Sowing date	10th may; 28th May; 15th June.			
15	B.C.G.A. Farm, Khanewal.	1939	Light sandy with saline patches.	Cotton.	Nitrogen ..	Control; 33 lb., N. p.a., at flowering in subplots.	4 blocks. 24 mainplots. 48 subplots.	(a) 32×104	1/13
					Watering	Normal, Heavy from mid-August.		(b) 32×104	1/13
					Sowing date ..	7th May; 30th may; 5th July.			

(viii) Appendix Giving Details of All Experiments from 1937-1942—(contd.)

Note :—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
16	Chak 90/9L Montgomery.	1939	Sandy loam with saline subsoil.	Cotton ..	Nitrogen ..	Control; 33 lb. N.p.a. at flowering in subplots.	4 blocks. 32 main plots 64 subplots.	(a) 30×93.5	1/15.5
					Watering ..	Normal; Heavy from mid-August.		(b) 30×93.5	1/15.5
					Sowing date ..	12th May; 20th June.			
					Variety	4F, Mollisoni 39.			
17	Agricultural Research Station, Montgomery.	1939	Sandy loam with highly saline subsoil.	Cotton ..	Nitrogen ..	Control; 50 lb. N. at flowering p.a. in sub-plots.	4 blocks. 16 plots. 32 subplots.	(a) 12×93	1/39
					Watering ..	Normal; Heavy from mid-August		(b) 12×93	1/39
					Sowing date ..	5th May; 13th June.			
18	Convillepur Farm, Montgomery.	1940	Light sandy with saline subsoil	Miscellaneous.	Nitrogen	Control; 33 lb. N. p.a. at flowering.	6 blocks. 48 mainplots 144 subplots.	(a) 16×96	1/28.3
					Varieties ..	289F/43; 289F/K25; Mollison 39; in subplots.		(b) 10.6×85	1/48
					Sowing date ..	8th May; 23rd May; 7th June; 22nd June.			
19	Risalewala Seed Farm, Lyallpur.	1940	,,	Toria and Gram.	Varieties ..	15 Punjab-American varieties and 3 desi varieties in subplots.	6 blocks. 24 main plots 432 subplots.	(a) 4×119.	1/91.5
					Sowing date ..	8th May; 23rd May; 7th June 23rd June.		(b) 4×100.8	1/108
20	Brucepur Farm, Lyallpur.	1940	,,	Fallow ..	Nitrogen ..	Control; 33 lb. N. p.a. at flowering.	3 replicates. 6 blocks (by confounding) 48 main plots. 144 subplots.		
				Gram ..	Sowing date ..	8thMay; 23rd May; 8th June; 23rd June.		(a) 16.5×107	1/24.6
					Variety	289F/43; L.S.S.; Mollisoni 39; in subplots.		(b) 11×99	1/40
					Watering.. ..	Normal; Heavy from mid-August.			
21	B.C.G.A. Farm, Khanewal.	1940	,,	Wheat ..	Nitrogen ..	Control; 33lb. N p.a. at flowering.	,,	(a) 13.3×105	1/31.1
					Variety	289F/43; 289F/K25; Mollisoni 39; in subplots.		(b) 8×90.75	1/60
					Watering.. ..	Normal; Heavy from mid-August.			
					Sowing date ..	13th May; 28th May; 14th June; 29th June.			

(*viii*) APPENDIX GIVING DETAILS OF ALL EXPERIMENTS FROM 1937-1942—(*Contd.*)

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
22	New Seed Farm, Sargodha.	1940	Light sandy and sandy loam with saline subsoil in patches.	Oil seeds	Nitrogen	Control; 33 lb. N. p.a. at flowering.	3 replicates. 6 blocks (by confounding) 48 main plots. 192 subplots.	(a) 15 × 99	1/29.3
					Variety	289F/43; 4F; L.S.S.; Mollisoni 39; in subplots.		(b) 10.6 × 90.75	1/45
					Watering	Normal; Heavy from mid-August.			
					Sowing date	15th May; 30th May; 15th June; 30th June.			
23	Montgomery Agricultural Station, Montgomery.		Light sandy and sandy loam with saline patches.	Cotton	Nitrogen	Control; 33 lb. N. p.a. at flowering.	3 replicates. 6 blocks (by confounding) 48 main plots 192 subplots.	(a) 14.5 × 94	1/31.9
				Wheat	Variety	289F/43; 289F/K25; 4F; Mollisoni 39; in subplots.		(b) 9.6 × 75.1	1/60
					Watering	Normal; Heavy from mid-August			
					Sowing date	10th May; 25th May; 9th June; 24th June.			
24	S. B. Ujjal Singh's Farm, Mianchannun.	,,	Light sandy with saline subsoil.	Wheat	Variety	289F/43; 289F/K25.	3 replicates. 6 blocks (by confounding) 24 main plots 72 subplots.	(a) 15.5 × 90	1/31.2
					Watering	Last irrigation on $w1$ = 30th Sept., $w2$ = 15th Oct., $w3$ = 30th Oct. in subplots.		(b) 10.3 × 78	1/54
					Sowing date	15th May; 30th May; 14th June; 29th June.			
25	Iqbal Estate, Iqbal Nagar.	,,	Sandy loam.	Cotton	Variety	289F/43; 289F/K25.	,,	(a) 12.5 × 94	1/37
					Watering	Last irrigation on $w1$ = 30th Sept., $w2$ = 15th Oct. $w3$ = 30th Oct.		(b) 7.5 × 80.6	1/72
					Sowing date	12th May; 27th May; 11th June; 26th June.			
26	Agricultural Farm, Multan.	,,	Light sandy with saline subsoil.	Wheat	Variety	289F/43; 289F/K25.	,,	(a) 19.3 × 79	1/28.5
					Watering	Last irrigation $w1$ = 30th Sept., $w2$ = 15th Oct., $w3$ = 30th Oct.		(b) 14.5 × 62.6	1/48
					Sowing date	10th May; 25th May; 11th June; 3rd July.			

(*viii*) Appendix Giving Details of All Experiments from 1937-1942—(*contd.*)

Note:— Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (*a*) at sowing. (*b*) at picking.	Subplot area in acre.
27	Agricultural Farm, Lyallpur.	1941	Sandy loam with saline subsoil.	Cotton ..	Sowing date ..	21st May ; 23rd June	16 blocks. 32 plots.	(*a*) 16 × 32 (*b*) 12 × 23.6	1/85 1/153.6
28	,,	,,	Light sandy ..	Wheat ..	Nitrogen ..	Control ; 48lb N. p.a. at flowering in subplots.	3 replicates. 6 blocks (by confounding) 24 main plots 48 subplots.	(*a*) 15 × 63.5	1/45.7
					Variety	4F ; Mollisoni 39.		(*b*) 10 × 54.45	1/80
					Watering.. ..	Normal; Heavy from mid-August.			
					Sowing date ..	15th May ; 10th June.			
29	,,	,,	,,	,,	Ridge	Flat ; Ridge.	4 blocks. 32 main plots. 64 subplots.	(*a*) 10 × 30	1/145.2
					Variety	4F, 289F/124 in subplots.			
					Watering.. ..	Normal ; Heavy from mid-August.		(*b*) 6 × 20	1/363
					Sowing date ..	23rd May ; 13th June.			
30	,,	,,	Light sandy ..	Oil seeds .	Nitrogen ..	Control ; 48 lb. N. p.a. at sowing ; 48 lb. N. p.a. at flowering.	2 replicates. 6 blocks (by confounding) 54 main plots. 108 subplots.	(*a*) 14 × 63.5	1/49
					Variety	4F, L.S.S., 289F/43.		(*b*) 10 × 54.45	1/80
					Spacing	Close wide ; in subplots.			
					Sowing date ..	13th May ; 1st June ; 20th June.			
31	Military Farm, Okara.	,,	Light sandy ..	Cotton ..	Nitrogen ..	Control ; 33 lb. N. p.a. at flowering.	5 replicates. 10 blocks (by confounding) 40 main plots 80 subplots.	(*a*) 20 × 105	1/20.7
					Potash	Control ; 230 lb. K20 p.a. three months before sowing.		(*b*) 15 × 96.8	1/30
					Phosphorus ..	Control ; 200 lb. P2O5 p.a. three months before sowing.			
					Sowing date ..	13th May ; 20th June ; Var. = 289 F/43.			

(viii) Appendix Giving Details of All Experiments from 1937-1942—(contd.)

Note :— Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
32	B.C.G.A. Farm, Khanewal.	1941	Light sandy with saline subsoil.	Fallow ..	Nitrogen ..	Control; 33 lb. N. P.a. at flowering.	4 replicates. 8 blocks (by confounding) 32 mainplots. 64 subplots.	(a) 20 × 105	1/20.7
					Potash.. ..	Control; 230 lb. K2O p.a. three months before sowing.		(b) 15 × 80.6	1/36
					Phosphorus ..	Control; 200 lb. P2O5 p.a. three months before sowing.			
					Sowing date ..	22nd May; 22nd June. Var.= 289F/K25.			
33	S. B. Ujjal Singh's Farm, Mian-channun.	„	„	Wheat ..	Variety	289F/43; 289F/K25.	3 replicates. 6 blocks. 24 mainplots. 72 subplots.	(a) 14 × 102	1/30.5
					Watering ..	Last irrigation on $w1$ = 30th Sept., $w2$ = 15th Oct., $w3$ = 30th Oct.		(b) 8 × 90.75	1/60
					Sowing date ..	18th May; 3rd June; 18th June; 10th July.			
34	Iqbal Estate, Iqbal Nagar.	„	Sandy loam.	Cotton ..	Variety . ..	289F/43; 289F/K25.	„	(a) 16 × 94	1/28.9
					Watering ..	Last watering on $w1$ = 30th Sept., $w2$ = 15th Oct., $w3$ = 30th Oct.		(b) 10 × 80.6	1/54
					Sowing date ..	17th May; 5th June; 17th June; 30th June.			
35	Agricultural Research Station, Montgomery.	„	Sandy loam with saline subsoil.	Cotton ..	Variety	289F/43; 289F/K25; 289F/124.	3 replicates. 6 blocks. 54 main plot 108 subplots.	(a) 18 × 94	1/25.7
					Watering ..	Last watering on $w1$ = 30th Sept., $w2$ = 15th Oct., $w3$ = 30th Oct.		(b) 12 × 80.6	1/45
					Spacing	Close: wide in subplots.			
					Sowing date ..	15th May; 8th June; 24th June.			
36	Agricultural farm, Multan.	1941	Light sandy with saline subsoil.	Wheat ..	Nitrogen	Control; 33 lb. Np.a. at flowering.	3 blocks. 27main plots. 54 transverse subplots. 81 longitudinal subplots (array strip) 162 total subplots.	(a) 8 × 82.5	1/66
					Variety	289F/43; 289F/K25; 289F/124.			
					Spacing	2ft. × ¾ft.; 2ft. × 1½ft.; 2ft. × 2¼ft in subplots.			
					Sowing date ..	19th May; 6th June; 24th June.		(b) 4 × 72.6	1/150

(viii) Appendix Giving Details of All Experiments from 1937-1942—(*contd.*)

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (*a*) at sowing. (*b*) at picking.	Subplot area in acre.
37	Agricultural Farm, Lyallpur.	1941	Sandy loam with saline subsoil.	Cotton ..	Spacing	1ft. × 1ft.; 1½ft. × 1½ft.; 2ft. × 2ft. 2½ft. × 2½ft.	6 blocks. 24 plots.	(*a*) 12.5 × 69 (*b*) 8 × 60.5 = 7½ × 60.5	1/50.5 1/90 1/96
38	"	1942	"	"	Spacing	1ft. × 1ft.; 1½ft. × 1½ft.; 2ft. × 2ft.; 2½ft. × 2½ft.	6 blocks. 48 plots.	(*a*) 17.5 × 46	1/54.1
					Variety	4F ; 289F/124.		(*b*) 12.5 × 36.3	1/96
39	B.C.G.A. ..	1940	All types of soil.	Wheat ..	Sowing date ..	19th May ; 5th June ; 20th June ; 5th July.	12 blocks ; 48 plots.		1/2
40	Farm	1941	"	"	" " ..	" " " " "	10 blocks ; 40 plots.		1/2
41	Khanewal ..	1942	"	"	" " ..	" " " " 22nd June, 15th July (resown).	12 blocks ; 48 plots.		1/2
42	Agricultural Farm, Lyallpur.	1941	Sandy loam with saline subsoil.	Cotton ..	Nitrogen ..	Control ; 40 lb. N p.a. at flowering.	4 replicates. 8 blocks (by confounding) 32 plots.	(*a*) 12 × 70	1/51.9
					Potash	Control ; 200 lb. K2O p.a. at sowing.		(*b*) 7 × 62.3	1/100
					Phosphorus ..	Control ; 100 lb. P2O5 p.a. at sowing.			
43	"	"	Light sandy ..	Oil seeds.	Nitrogen ..	Control ; 50lb. N p.a. at sowing ; 100 lb. N p.a. at sowing.	6 blocks. 18 plots.	(*a*) 14 × 63.5 (*b*) 10 × 55	1/49 1/79.3
44	New Seed Farm, Sargodha.	"	Light sandy ..	"	Nitrogen ..	Control; 33 lb. N p.a. at flowering	4 blocks. 24 main plots. 48 subplots.	(*a*) 18 × 99	1/24.4
					Variety	4F ; L.S.S. ; in subplots.			
					Sowing date ..	15th May ; 2nd June ; 19th June.		(*b*) 12 × 96.75	1/40
45	B.C.G.A. Farm, Khanewal.	1942	Light sandy with saline subsoil.	Cotton ..	Nitrogen ..	Control ; 33 lb. N p.a. at flowering in subplots.	4 replicates. 8 blocks (by confounding) 32 main plots 64 subplots.	(*a*) 20 × 105.	1/20.7
					Potash	Residual effect of potash applied in 1941 (Expt. 32). 64		(*b*) 15 × 89.6	1/36
					Phosphorus ..	Residual effect of phosphorus applied in 1941 (Expt. 32).			
					Sowing date ..	22nd May ; 22nd June, Var.—289F/K25.			

(*viii*) Appendix Giving Details of All Experiments from 1937-1942—(*contd.*)

Note :—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place.	Year.	Soil type.	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (*a*) at sowing. (*b*) at picking.	Subplot area in acre.
46	Military Farm, Okara.	1942	Light sandy with alkaline patches.	Cotton ..	Nitrogen ..	Control ; 33 lb. N p.a. at flowering in subplots.	5 replicates. 10 blocks (by confounding) 40 main plot 80 subplots.	(*a*) 20 × 105	1/20.7
					Potash	Residual effect of potash applied in 1941 (Expt. 31).		(*b*) 16 × 90.7	1/30
					Phosphorus ..	Residual effect of P2O5 applied in 1941 (Expt. 31).			
					Sowing date ..	13th May ; 20th June. Var.= 289F/43.			
47	S. B. Ujjal Singh's Farm, Mian-channun.	,,	Light sandy with saline subsoil.	Gram (rice reclaimed).	Nitrogen ..	Control ; 33 lb. N p.a. at sowing ; 33 lb. N p.a. at flowering.	2 replicates. 6 blocks. 54 plots.	(*a*) 18 × 104	1/23.3
					Variety	289F/43 ; 289F/K25 ; 289F/124.		(*b*) 10 × 80.6	1/54
					Sowing date ..	19th May ; 6th June ; 26th June.			
48	,,	,,	,,		Variety	289F/43 ; 289F/K25.	4 blocks. 12 main plots. 48 subplots.	(*a*) 15 × 50	1/58.1
					Spacing	Rectangular Block : 1½ft. × ¾ft. ; 2¼ft. × 1ft. 3ft. × 1½ft.		(*b*) 9 × 40.3	1/120
						Square Block ; 1ft. × 1 ft. ; 1½ ft. × 1½ft. 2 ft. × 2 ft.			
49	Agricultural Farm, Lyallpur.	,,	Sandy loam with saline subsoil.	Cotton ..	Nitrogen ..	Control ; 50 lb. N p.a. at flowering in transverse plots.	12 blocks. 36 longitudinal plots. 24 transverse plots.	(*a*) 18 × 33	1/73.3
					Sowing date ..	28th April ; 23rd May ; 15th June ; in longitudinal plots.		(*b*) 12 × 25.2	1/144
50	,,	,,	Light sandy ..	Oil seeds .	Nitrogen ..	Control ; 33 lb. N at sowing; 66 lb. N at sowing, 33 lb. N at flowering; 66 lb. N at flowering, all p.a.	4 blocks. 60 plots.	(*a*) 33 × 60.5	1/21.8
								(*b*) 15 × 48.4	1/60
					Sowing date ..	21st May ; 11th June ; 2nd July.			

(viii) Appendix Giving Details of All Experiments from 1937-1942.—(concld.)

Note:—Nitrogen is given in the form of sulphate of ammonia except where stated.

Expt. No.	Place	Year.	Soil type	Previous crop.	Factors studied.	Level of each factor.	Lay out.	Subplot dimensions in ft. (a) at sowing. (b) at picking.	Subplot area in acre.
51	Agricultural Farm, Lyallpur.	1942	Light sandy with alkaline patches.	Cotton ..	Nitrogenous manures.	(a) Control, (b) sulphate of ammonia, (c) toria cake, (d) cotton cake all @ 50 lb. N p.a. at sowing.	8 blocks. 32 plots.	(a) 17.5 × 60.5 (b) 12.5 × 48.4	1/41.1 1/72
52	,,	,,	Light sandy ..	Oil seeds .	Nitrogen ..	(a) Control ; (b) sulphate of ammonia, (c) toria cake.	3 blocks. 36 plots.	(a) 16 × 60.5	1/45
					Organic manures.	(a) Control ; (b) 20 tons F.Y.M., (c) 15 mds. molasses ; (d) 30 mds. molasses, all at 50 lb. N p.a. at flowering.		(b) 12 × 48.4	1/75
53	,,	1942	Light sandy ..	Cotton ..	Toria cake ..	(a) Control ; (b) 50 lb. N at sowing; (c) 50 lb. N at flowering p.a.	4 blocks. 36 main plots. 72 subplots.	(a) 15 × 31.5	1/92.2
					Spacing between rows.	1½ ft. ; 2 ft. ; 2½ ft.		(b) 10 × 24.2	1/180
					Spacing between plants.	1 ft. ; 2 ft. in subplots.			
54	Iqbal Estate, Iqbal Nagar.	,,	Sandy loam ..	,,	Nitrogen ..	Control ; 50 lb. N p.a. at flowering	3 replicates. 6 blocks. (balanced arrangement). 72 plots.	(a) 16 × 94	1/28.9
					Cotton cake ..	Control ; ,, ,, at sowing.		(b) 10 × 80.6	
					Toria cake ..	Control ; ,, ,, at sowing.			1/54
					Variety	289F/43 ; 289F/124.			
					Sowing date ..	20th May ; 7th June ; 27th June.			

CHAPTER X.

MANURING OF COTTON IN THE PUNJAB.

Manuring of cotton as of other crops is one of the basic problems in agriculture and forms an important part in any programme for crop improvement. Previous work done in the Punjab revealed that the applications of phosphate and potash to cotton proved ineffective while the response to nitrogen varied from place to place and season to season (Vaidyanathan, 1934 and Dept. of Agriculture Punjab, 1936). In certain cases the response was spectacular, in others meagre. These findings were important in as much as they suggested the elimination of the two major nutrients, phosphates and potash, from any manurial programme, but they were of restricted value as no definite conclusion could be arrived at with respect to nitrogen application as a general practice. The causes for the variations in the utility of nitrogenous manures ought to be explained before they could be recommended for wide adoption.

The low nitrogen status of the soils in India gave Crowther (1939) the impression of great prospects of the use of sulphate of ammonia in this country. Experience in the Punjab has, however, shown that low nitrogen contents of the soil is not always attended with high response to this fertilizer in case of cotton. The success or the failure of manuring depends not only on the knowledge of the nutrient limiting but also on the controlling influence of other factors associated with it. These factors may be different in different countries and hence require independent study.

It has already been pointed out (Dastur, 1941a) that deficiency of nitrogen produces *tirak* symptoms in the Punjab-American cottons on light sandy soils. The effect of nitrogen application as sulphate of ammonia, in combination with varying levels of other factors, was, therefore, studied on different soil types in a large number of complex experiments conducted during 1937-1942 in the course of *tirak* investigations. The results of some of the experiments showing the effect of nitrogen on the various phases of plant activity on light sandy soils have since been reported (Dastur and Mukhtar Singh, 1943 and 1944). The present contribution is devoted to a concise account of the practical aspect of cotton manuring based on the results of the numerous experiments distributed over the important American-cotton growing tracts of the province (Dastur and Sucha Singh, 1944).

In all, 36 replicated field trials on lands representing different soil conditions were conducted. Nearly 60 per cent of them were carried out on the Departmental Agricultural Farms and the rest at the private estates. The experiments were mainly of the multiple-factor type (*vide* Appendix at the end of Chapter IX). Sowing date as a factor was introduced in the bulk of the trials, as preliminary studies had shown this factor to influence greatly the yield and the boll opening of cotton. A few experiments also included spacing types. The relation of nitrogen with other factors such as variety, watering, phosphorus, potash etc., was also explored. Some experiments also provided information as to the time of application, the levels and the forms of nitrogen.

Relevant information pertaining to the individual experiments and the nature of the soil under them is consolidated in the Appendix at the end of Chapter IX. In the majority of cases, soil samples were taken before the experiments were laid out and were later analysed to determine the nature of soil conditions. In a few cases, however, the characteristic symptoms of the plants and the texture of the surface soil broadly indicated the soil type.

The yields of the control and the manured plots, averaged over all levels of the remaining factors, and the mean response to nitrogen along with appropriate standard errors are given in the last three columns of the two tables. The experiments have been grouped according as: (a) the increase in yield with nitrogen was high or medium and definitely profitable (Table XLVIII) (b) the response was low or nil involving monetary loss (Table XLIX). The price of sulphate of ammonia has been taken at its pre-war rate of Rs. 5 per maund (82.2 lb.) and that of seed cotton at its lowest value of Rs. 7 per maund.

A study of the results given in Tables XLVIII & XLIX will show that the response to manuring with sulphate of ammonia on yield was high and profitable in 20 experiments while it was low and unprofitable in the remaining 16 experiments. Thus chances for the success and the failure of manuring cotton in the Punjab were found to be nearly equal.

It could also be seen from the same Table that the increase in yield obtained by the application of a unit dose of sulphate of ammonia was not governed by the general yielding capacity of a field. Fields producing as low as 1 to 7 maunds of *kapas* per acre have not responded to manuring (Expts. 2, 9, 15, 16, 17, 32 in Table XLIX), while fields with a higher yielding capacity have been found to give high and profitable returns with the application of sulphate of ammonia (Expts. 4, 10, 14, 28, 30, 36 and 43 in Table XLVIII.) Thus the level of yield in a field was no index for manuring of cotton in the Punjab. It indicated that soil factors other than nitrogen status of the soil operated in determining the response to manuring. The investigations carried out in the Punjab Physiological (Cotton failure) Scheme have made it possible to distinguish the soil conditions where manuring would be profitable and where it would involve monetary loss.

(i) Factors that Influence the Response to Sulphate of Ammonia.

Soil Conditions.

A study of the soil in several parts of the Punjab in relation to the effect produced by sulphate of ammonia on the growth and yield of cotton revealed that on light sandy soils free from subsoil salinity or alkalinity a very heavy response to manuring was obtained. The response was particularly high if the cotton followed wheat or an oilseed crop (Table XLVIII). The increase in yield was of a medium order if such fields were allowed to recuperate through fallowing (Expt. 1).

Salinity or alkalinity or high pH in the subsoil was found to affect adversely the response to manuring. Although the fields having these subsoil conditions differed widely in their yielding capacity without manuring, the application of sulphate of ammonia was found to be unprofitable in all cases (Table XLIX). This held good for the organic manures as well (Table LVI).

Table XLVIII.

(a) Experiments in which response to sulphate of ammonia was high and profitable.

(Further details for each experiment are given at the end of Chapter IX).

Expt. No.	Dose and time of application of sulphate of ammonia.	Yield of seed cotton in mds. per acre.	Response over Control.	S. E. of Response.
1	Control	19.25	..	..
	22 lb. N. at sowing+ ..	22.74	3.49**	0.55
	28 lb. N at flowering ..			
4	Control	12.86	..	..
	50 lb. N at sowing	20.96	8.10**	..
	50 lb. N at flowering	22.11	9.25**	1.03
	50 lb. N at sowing+ ..	25.82	12.96**	..
	50 lb. N at flowering ..			
6	Control	4.31	..	..
	25 lb. N at sowing+ ..	7.50	3.19**	0.88
	25 lb. at flowering ..			
10	Control	7.94	..	..
	50 lb. N at flowering	13.95	6.01**	0.49
11	Control	9.55	..	..
	33 lb. N at flowering	14.34	4.79**	0.41
12	Control	9.94	..	..
	25 lb. N at flowering .. .	13.26	3.32**	0.32

Expt. No.	Dose and time of application of sulphate of ammonia	Yield of seed cotton in mds. per acre.	Response over Control.	S. E. of Response.
14	Control	8.52	..	..
	16 lb. N	9.52	1.00	..
	32 lb. N	11.34	2.82*	1.19
	48 lb. N	13.27	4.75**	..
18	Control	14.03	..	..
	33 lb. N at flowering	16.84	2.81**	0.57
22	Control	8.52	..	..
	33 lb. N at flowering	10.53	2.01**	0.53
28	Control	9.87	—	..
	48 lb. N at flowering	18.44	8.57**	0.25
30	Control	16.89	..	..
	48 lb. N at sowing	22.25	5.36**	0.46
	48 lb. N at flowering	22.14	5.25**	..
36	Control	9.50	..	..
	33 lb. N at flowering	15.00	5.50**	0.84
43	Control	17.63	..	..
	50 lb. N at sowing	25.21	7.58**	..
	100 lb. N at sowing	25.31	7.68**	0.80

Table. XLVIII—*concluded.*

(a) *Experiments in which response to sulphate of ammonia was high and profitable*—concluded.

(Further details for each experiment are given at the end of Chapter IX).

Expt. No	Dose and time of application of sulphate of ammonia.	Yield of seed cotton in mds. per acre.	Response over Control.	S. E. of Response.
44	Control	9.36	..	..
	33 lb. N at flowering	12.26	2.90**	0.57
45	Control	17.05	..	..
	33 lb. N at flowering	19.15	2.10**	0.55
46	Control	11.84	..	..
	33 lb. N at flowering	15.17	3.33**	0.39
47	Control	8.82	..	..
	33 lb. N at sowing	10.40	1.58**	..
	33 lb. N at flowering	11.98	3.16**	0.49

Expt. No.	Dose and time of application of sulphate of ammonia.	Yield of seed cotton in mds. per acre.	Response over Control.	S. E. of Response.
50	Control	7.64	..	..
	33 lb. N at sowing	10.58	2.94**	..
	66 lb. N at sowing	12.27	4.63**	0.65
	33 lb. N at flowering	10.48	2.84**	..
	66 lb. N at flowering	12.54	4.90**	..
52	Control	15.58	..	..
	50 lb. N at flowering	18.68	3.10**	0.45
54	Control	15.59	..	..
	50 lb. N at flowering	18.83	3.24**	0.67

TABLE XLIX.

(b) *Experiments where response to sulphate of ammonia was low involving monetary loss.*

(Further details for each experiment are given at the end of Chapter IX.)

Expt. No.	Dose and time of application of sulphate of ammonia	Yield of seed cotton in mds. per acre	Response over Control	S. E. of Response
2	Control	4.17	..	..
	50 lb. N at sowing	5.03	0.86	0.90
3	Control	7.64	..	..
	25 lb. N at sowing + .. } 50 lb. N at flowering ..	11.25	3.61**	1.51
5	Control	21.20	..	..
	50 lb. N at sowing	22.95	1.75	2.16
8	Control	13.82	..	..
	50 lb. at flowering	13.41	—0.41	1.06
9	Control	4.01	..	..
	25 lb. N at sowing + .. } 25 lb. N at flowering ..	5.10	1.09	2.82
15	Control	1.48	..	..
	33 lb. N at flowering	1.68	0.20*	0.09
16	Control	7.08	..	..
	33 lb. N at flowering	7.95	0.87**	0.29
17	Control	1.32	..	..
	50 lb. N at flowering	1.42	0.10	0.17

Expt. No.	Dose and time of application of sulphate of ammonia	Yield of seed cotton in mds. per acre	Response over Control	S. E. of Response
20	Control	14.52	..	..
	33 lb. N at flowering	15.67	1.15	1.02
21	Control	13.35	..	..
	33 lb. N at flowering	15.13	1.78**	0.55
23	Control	9.47	..	..
	33 lb. N at flowering	10.51	1.04	0.44
31	Control	9.20	..	..
	33 lb. N at flowering	10.69	1.49**	0.26
32	Control	6.57	..	..
	33 lb. N at flowering	7.40	0.83**	0.22
42	Control	21.66	..	..
	40 lb. N at flowering	22.89	1.23	3.03
49	Control	15.09	..	..
	50 lb. N at flowering	15.68	0.59	0.66
51	Control	8.82	..	..
	50 lb. N at flowering	10.77	1.95	1.48

The above two soils conditions are found irregularly distributed in the cotton fields. Fields with light sandy soil may also possess patches of subsoil salinity or alkalinity in varying proportions. The average increase in yield by manuring such a field would, therefore, depend on the relative proportion of such areas present in the subsoil. The variations in response to manuring can be partly understood in the light of the above findings. It also indicates why a general recommendation for manuring of cotton in the Punjab could not be made as was done for Egypt by Crowther *et al.* (1937). Other relevant factors found to influence the response to manuring on light sandy soil are briefly mentioned below :

Varieties.

Where as the *desi* variety, Moll. 39 (*G. indicum*), gave a high and proytable response to nitrogen on all soil types, the ability of the Punjab-American cottons (*G. hirsutum*) to give such increases in yield with manuring was greatly restricted by the subsoil conditions (Table L).

Another important fact that emerged from this study was that the response to nitrogen of the different varieties varied in the order of their yielding capacity. Of all cottons, Moll. 39 gave the maximum yield as well as the highest response to nitrogen in all cases except in Expt. 11 where the germination and the subsequent stand of this variety was poor on account of patches of alkali on the soil surface.

L.S.S. yields were heavier than 4F and the response to nitrogen was also found to be greater in the former than in the latter (Expts. 22, 30, 44). The remaining strains, *viz.*, 289F/43, 289F/K25 and 289F/124 did neither differ significantly in their yielding capacity nor in their responsiveness to nitrogen.

Sowing time.

The sowing time of cotton was another factor that governed the response to manuring. It was found that generally the May-sown crop gave higher increases in yield by manuring than the June-sown crop (Table LI). The reduction in the magnitude of response was spec'ally marked in the crop sown during the second half of June. If the soils were extremely deficient in nitrogen as in Expts. 11, 36, 47 & 18, all the sowings gave equally pronounced increases in yield by manuring. With higher doses of sulphate of ammonia on such fields the same relationship of sowing time with nitrogen application would have probably held good. As the June-sowings of American cottons have now been recommended as a preventive measure against *tirak*, this aspect of manuring must be clearly borne in mind.

Spacing.

There was an indication that for manurial response the May-sown crop behaved indifferently to spacing, but close spacing was specially conducive to better fertilizer response in the case of June-sowings (Table LII). The experimental evidence in favour of this view is, however, still not conclusive.

TABLE L.

Increase in yield with sulphate of ammonia under different varieties and its relation to their yielding capacity.

Expt. No.	Dose of manure at flowering (mds. per acre.)	† Increase in yield over control with manure (maunds per acre).						S. E.	Order of varietal mean yields.
		Moll. 39.	4F	L. S. S.	289F/43.	289F/k25.	289F/124.		
12 (Lyallpur)	1½	3.98*	2.66**	....	..	..	..	0.45	Moll. 39 > 4F.
30 ,, ...	3	..	5.28**	5.56**	4.89**	..	..	0.80	L. S. S. > 4F > 43F.
28 ,, ...	3	10.66**	6.47**	..	..	..	..	0.36	Moll. 39 > 4F.
22 (Sargodha)	2	4.00**	1.48	2.36	0.22	..	..	0.95	Moll.39 > L.S.S. > 4F > 43F
44 ,, ...	2	..	1.80	3.99**	..	..	..	0.81	L. S. S. > 4F.
11 (Multan)	2	3.43**	6.16**	..	..	..	..	0.58	4F > Moll. 39.
36 ,, ...	2	..	..	..	4.14**	7.35**	5.01**	1.45	Varieties and varieties × nitrogen insignificant.
47 ,, ...	2	..	..	..	3.08**	3.43**	2.97**	0.84	....
18 (Montgomery) ..	2	5.78**	..	..	2 34**	0.30	..	0.82	Moll. 39 > 43F > K25.
54 ,, ...	3	..	..	..	3.17**	..	3.32**	0.82	Varieties insignificant.
20 (Lyallpur)	2	2.49	..	0.92	0.05	..	..	1.33	Moll. 39 > L.S.S. > 43F.
21 (Multan)	2	3.75**	..	..	0.79	0.78	..	0.98	Moll. 39 > K25 > 43F.
16 (Montgomery) ..	2	1.22**	0.54	..	..	..	..	0.29	Moll. 39 > 4F.

† Mean yields of control and manured plots have not been given separately.

TABLE LI.

Variation in yield response to sulphate of ammonia with changing sowing date.

Expt. No.	Dose of manure at flowering (mds. per acre.)	† Increase in yield with manure (mds. per acre). 1—15 May.	16—31 May.	1—15 June.	After 15 June.	S. E.
10	3	(12 May) 7.85**	..	(2 June) 6.88**	(22 June) 3.29**	0.85
6	1½+1½ at sowing.	(1 May) 4.36**	..	(1 June) 2.03	..	1.25
12	1½	(6 May) 4.08**	..	(10 June) 2.55**	..	0.45
14	3	(10 May) 5.37**	(28 May) 5.84**	(15 June) 3.03*	..	1.27
30	3	(13 May) 6.89**	(31 May) 5.05**	..	(20 June) 3.79**	0.80
28	3	(15 May) 9.22**	..	(10 June) 7.91**	..	0.36
50	2	..	(21 May) 4.85**	(11 June) 2.45*	(2 July) 1.21	1.13
50	4	..	(21 May) 7.70**	(11 June) 5.21	(2 July) 1.80	1.13
22	2	(15 May) 2.87**	(30 May) 3.85**	(15 June) 1.41	(30 June)—0.08	1.06
44	2	(15 May) 3.83**	..	(2 June) 3.25**	(19 June) 1.60*	0.81
11	2	..	(18 May) 4.07**	..	(18 June) 4.93**	0.58
36	2	..	(19 May) 4.51**	(6 June) 4.95**	(24 June) 7.04**	1.45
45	2	..	(22 May) 2.46**	..	(22 June) 1.73*	0.77
47	2	..	(19 May) 4.02**	(6 June) 2.05*	(26 June) 3.41**	0.84
18	2	(8 May) 3.15*	(23 May) 2.50*	(7 June) 3.52**	(22 June) 2.05	1.14
46	2	(13 May) 4.50**	..	..	(20 June) 2.16**	0.55
54	3	..	(20 May) 5.24**	(7 June) 2.31*	(27 June) 2.19	1.15

† Mean yields of control and manured plots have not been given separately.

TABLE LII.

The effect of spacing on the response to nitrogen under different sowing dates.

Expt. No.	Dose of manure at flowering (mds. per acre.)	Increase in yield with manure (maunds per acre). 1-15 May. Close spacing.	1-15 May. Wide spacing.	16-31 May. Close spacing.	16-31 May. Wide spacing.	1-15 June. Close spacing.	1-15 June. Wide spacing.	16-30 June. Close spacing.	16-30 June. Wide spacing.	S. E.
10	3	8.05**	7.64**	..	..	9.05**	4.70**	4.73**	1.85	1 20
12	1½	3.78**	4.37**	..	..	2.60**	2.51**	..	..	0.64
30	3	6.03**	7.76**	4.62**	5.49**	..	..	5.14**	2.44**	0.85

Watering.

Heavy watering greatly favoured the effectiveness of manure in Expt. 1 where the field was allowed to recuperate through fallowing prior to sowing cotton

(Table LIII). Under intensive system of cropping, however, nitrogen alone acted as a limiting factor and the increases in yield with the artifical fertilizer were so heavy under normal watering that further improvement in response through extra dose of water was meagre (Expts. 4, 10, 28, 11). Hence heavy watering on nitrogen deficient soils would not be of much benefit whether given with or without the application of a nitrogenous fertilizer.

TABLE LIII.

Interaction of nitrogen and watering.

Expt. No.	Dose of manure at flowering (mds. per acre).	Increase in yield with manure (maunds per acre.)			
		Normal watering.	Heavy watering.	S. E.	Previous crop.
1	$1\frac{3}{4}$	1.09	5.89^{**}	0.78	Cultivated fallow.
4	,,	8.82^{**}	9.69^{**}	1.46	Oil seeds.
10	,,	5.82^{**}	6.18^{**}	0.69	,,
28	,,	8.53^{**}	8.61^{**}	0.36	Wheat.
11	2	4.34^{**}	5.26^{**}	0.58	Cotton.

Time of application.

Optimum time for the application of sulphate of ammonia was unmistakably mid-August for the May-sown cottons (Table LIV). This confirms the previous experience in the Punjab (Dept.; Agric. 1936). The differences in favour of August application were less marked as the sowings were delayed, so much so that in a few cases (Expts. 30, 50) application before sowing proved slightly superior for the late sowing.

TABLE LIV.

Time of application of sulphate of ammonia and its relation to the date of sowing.

Expt. No.	Dose of manure (mds. per acre).	Increase in yield with manure (maunds per acre).								S. E.	Remarks.
		1-15 May.		16-31 May.		1-15 June.		16-30 June.			
		Early.	Late.	Early.	Late.	Early.	Late.	Early.	Late.		
4	3	..	..	8.10^{**}	9.25^{**}	..	..	..	..	1.03	Early = Manure applied before sowing.
14	2	1.68	5.34^{**}	3.59^{*}	4.59^{*}	1.79	2.68	..	..	1.79	
30	3	6.13^{**}	6.89^{**}	5.40^{**}	5.05^{**}	..	..	4.54^{**}	3.79^{**}	0.80	Late = Manure applied in August.
50	2	..	..	3.49^{**}	4.85^{**}	3.28^{**}	2.45^{*}	2.04	1.21	1.13	
47	2	..	..	1.32	4.02^{**}	1.78^{*}	2.05^{*}	1.64^{*}	3.41^{**}	0.84	

Dose of manure.

There were only a few trials involving the comparisons of the different doses of ammonium sulphate. A study of Table XLVIII reveals that the increase in yield is linear up to 3 maunds of manure per acre (Expt. 14). The response trend shows a decline with higher rates of application (Expt. 50), and 6 maunds of sulphate of ammonia is undoubtedly an overdose (Expts. 4 and 43). In the experiments under review, the dose employed was 2 to 3 maunds. The results obtained and discussed, therefore, are of general practical value.

(*ii*) Effect of Phosphatic and Potassic Fertilizers.

There were seven trials to study the effect of these fertilizers with and without nitrogen. Two experiments were repeated on the same sites to find out the residual effect, if any. In spite of the heavy doses used, the direct as well as the residual effects of these fertilizers were insignificant in all cases (Table LV). In view of these results and those already obtained by the Department of Agriculture, it can safely be concluded that the Punjab soils do not lack in phosphorus or potash. Besides, none of these fertilizers interacted with nitrogen, the level of which alone determined the final yield.

TABLE LV.

Effect of phosphorus and potash on the yield of cotton.

Expt. No.	Dose of Phosphate (lb. P_2O_5 per acre.)	Dose of Potash (lb. K_2O per acre.)	Yield of *kapas*† in maunds per acre.				
			Control.	Phosphorus.	Potash	Phosphorus. + Potash.	S.E. of Mean.
1	120	48	20.3	21.7	20.6	21.4	0.55
4	100	200	20.4	19.9	20.7	20.8	0.73
12	50	50	11.2	..	..	12.0	0.38
3	..	360	8.98	..	11.2	..	1.07
42	100	200	22.5	22.4	21.7	22.4	3.03
32	200	230	7.44	6.95	6.99	6.56	0.69
31	200	230	10.8	9.25	9.44	10.3	0.44
45	Residual Effect of Expt. 32		17.6	17.8	19.1	17.9	1.17
46	Residual effect of Expt. 31.		13.0	13.5	13.8	13.7	0.63

† *Kapas* = seed cotton.

(*iii*) Effect of Organic Manures.

Farmyard manure and *berseem* (green manure) were tried in a few experiments. The results are summarised in Table LVI. The absence of response in Expt. 1 was attributable to three factors, *viz.*, (1) cotton followed cultivated fallow, (2) the dose was small and (3) this treatment was relegatd to the main plots. The soil under Expts. 5, 9 being sandy loam and saline was responsible for the failure of response to manuring. In other experiments, the increases in yield were substantial as the soil underneath was light and sandy. Thus these manures behaved in the same manner as did sulphate of ammonia in relation to soil conditions.

TABLE LVI.

Effect of Farmyard Manure and Berseem green manure on the yield of cotton.

Expt. No.	Dose (tons per acre).	Yield of *kapas* in maunds per acre.				
		Control.	Farmyard manure.	*Berseem* green manure.	Response.	S. E.
1	5	20.7	21.3	..	+0.6	0.78
6	10	4.31	..	7.31	+3.0**	0.88
52	20	13.4	22.6	..	+9.2**	0.90
3	20	7.64	11.86	10.05	+4.22** +2.41	1.51
5	10	21.2	19.5	..	—1.7	2.16
9	10	4.01	..	3.41	—0.60	2.82

On account of the non-availability of sulphate of ammonia under the present war situation, the comparative manurial value of oil cakes and ammonium sulphate was studied in the year 1942. Quantities of manure to supply 50 lb. N per acre were calculated and added. *Toria* cake though slightly inferior to sulphate of ammonia on equivalent nitrogen basis proved to be a good substitute for the latter (Table LVII). Cotton cake did not hold out promise of extensive use. There was an indication from Expt. 53 that *toria* cake should preferably be applied before sowing. Further work is, however, necessary to confirm these findings and to work out the economics of toria cake.

TABLE LVII.

Comparative effects of ammonium sulphate and oil cakes on the yield of cotton.

Expt. No.	Time of application of oil cakes.	Yield of *kapas* in maunds per acre.				
		Control.	*Ammonium sulphate.	Toria cake.	Cotton cake.	S. E. of mean.
52	at flowering.	13.24	17.02	16.19	..	0.38
54	,, sowing.	15.59	18.83	17.69	16.64	0.35
51	,, ,,	8.82	10.77	9.57	8.14	1.04
53	(*a*),, ,,	11.24	..	16.29	..	0.33
	(*b*),, flowering.	..	..	15.87	..	..

* Applied in all cases at flowering in the middle of August.

(*iv*) A Practical Method to Detect Nitrogen Deficient Fields.

Manuring of American cottons in the Punjab could be profitably undertaken on light sandy soils free from subsoil salinity. This finding could not be put to practical use as it was impossible for a *zamindar* to know the soil conditions and to exclude from manurial programme such fields as were not likely to yield profitable returns. Besides, the yielding capacity of a field was shown to be no criterion for manuring it. During the course of investigations carried out in the Punjab Physiological Scheme, a simple and inexpensive method has been found to detect cotton fields which would give profitable increase in yields by manuring with ammonium sulphate. This method is termed as "tannin" test, and is described below:

In the month of August, six cotton plants are selected at random from one fourth of an acre and 30 discs are cut out from mature leaves by means of a leaf punch. They are transferred to a tube containing about ½ oz. of water and the tube is kept for 2 hours in a hot water bath. When the extract of the leaf discs cools down, it is treated with 5 drops of an aqueous solution of osmic acid (1 gram of osmic acid dissolved in 4½ lb. or 2 litres of water). Two drops of dilute sulphuric acid are then added to the extract. If a blue green to a dark brown colour (Fig.4) is produced, the crop requires nitrogen manuring. If the leaf extract remains yellow or orange red, manuring is not necessary. The cost of making this test works out to be about one anna (*i.e.*, one penny per sample) at the pre-war rates of the chemicals etc. used.

"Tannin" test has been tried out extensively for three successive years on the fields of *zamindars* in the different cotton growing tracts of the Punjab, and found to be very successful. The details of the tests made and the results obtained are given in Table LVIII.

Table LVIII.

Statement of "tannin" test made and the results obtained.

Year.	Total No. of tests made.	No. of positive tests.	No. of fields selected for Manuring.	Dose of sulphate of amm. in mds. per acre.	Yield of *kapas* in mds. per acre.		Increase.
					Control.	Manured.	
1939 ..	45	22	15	2	7.21	11.21	4.0
1940 ..	265	123	55	2	10.48	12.66	2.18
1941 ..	326	173	22	2	11.38	14.24	2.86

The results show that it would be profitable to apply sulphate of ammonia to the fields that give the test. In 1940, the magnitude of increase was relatively small as the majority of fields selected for the test and subsequent manuring had already turned very pale, so that it was too late to correct the internal disorder in the plants at such an advanced stage of nitrogen starvation. Fields selected for

the test should be light green and should possess perfect stand in order to obtain best results from manuring. It may be mentioned that this test for manuring cotton has only been found successful in the Punjab. It is possible that similar results may not be obtained in other cotton tracts.

(*v*) Conclusions.

The problem of manuring cotton thus centres round the availability and the application of nitrogenous manures as phosphorus and potash have not generally been found to be limiting. Nevertheless the problem did not prove to be quite simple as the magnitude of response to nitrogen was found to be governed by a multitude of factors of which the soil was most important. While the *desi* variety could profitably be manured on a wide range of soil conditions, American cottons responded only on light sandy soils free from subsoil *kalar*. On sandy loam fields with saline or alkaline subsoils the response was either low or nil. The increase in yield was of a medium order when light sandy lands had also some alkali concentrations in the subsoil. Where the different soil conditions were found intermixed, the relative proportion of each determined the ultimate gain from the application of nitrogen. This finding explains at least in part the cause of wide variations in the results obtained with nitrogenous fertilizers and the difficulty experienced in making a general recommendation for cotton manuring.

A simple and expeditious device designated as the "tannin" test has been evolved and described, the use of which enables one to detect fields suffering from nitrogen deficiency without recourse to soil analysis. This biochemical test is applied to the aqueous extract of the leaf just before the onset of flowering. Once the positive test is obtained sulphate of ammonia can be applied at the rate of 2 to 3 maunds per acre.

The influence of sowing date, spacing, and variety in modifying the response to nitrogen on light sandy soils cannot be ignored. May-sowings possess greater potentiality for increase in yield through manuring than the June-sowings. The usefulness of nitrogen falls off as the sowing date advances, so much so that the June-end-sowings derive the least benefit. The manurial response to late-sowings can, however, be greatly improved by close spacing.

The different strains of cotton were found to respond to nitrogen in the order of their yielding capacity, *i.e.*, greater the yield, greater the response and *vice versa*.

The behaviour of the organic manures in relation to the soil conditions was similar to that of ammonium sulphate, and from two years' trials, *toria* cake appears to be a good substitute for this inorganic fertilizer.

CHAPTER XI.

RELATION OF WEATHER FACTORS WITH THE SPREAD OF *TIRAK*

It was explained in the foregoing Chapters what *tirak* was, how it developed on the two soil types and how it could be remedied. Though the soil conditions that produced *tirak* in the Punjab-American cottons were known, the causes for the more intense and widespread occurrence of *tirak* in certain years than in others remained to be explained. The widespread occurrence of *tirak* in certain years indicated that it occurred on lands where in other years normal crops grew. This was perhaps the main reason why soil factors were not at all considered and all stress was laid on weather factors alone by Milne (1922) and Trought (1931) in their attempts to explain the partial failures of American cottons in the Punjab.

Even though *tirak* was caused by certain soil conditions the possibility of weather factors playing their part in the spread of *tirak* cannot be ruled out, as soil conditions by themselves cannot evidently explain the failure years. It was, therefore, necessary to investigate the weather conditions which, by interacting with the soil conditions, may be causing widespread occurrence of *tirak* in the failure years.

The problem can be tackled in two ways by adopting standard statistical methods. The partial failure years were years of low yields. They were also the years when widespread occurrence of *tirak* in the Punjab-Americans had occurred. It was, therefore, necessary to determine if any correlation either between weather factors and yields or between weather factors and *tirak* existed. It was, therefore, first undertaken to see if any one of the weather factors either singly or in combination with other factors could be correlated with low yields.

A study of the yields of American and *desi* cottons per acre from 1921 to 1935 indicated upward trends in yields as already stated in Chapter II. It was, therefore, necessary to eliminate these progressive changes which may have occurred either on account of introduction of new varieties or by improved methods of cultivation, before the variations in yields caused by the annual fluctuations in weather factors could be studied.

As the weather conditions in the different American cotton districts are known to differ very appreciably it was not correct to take the annual average yields of the whole province. The yields of three important cotton-growing districts: Lyallpur, Montgomery and Multan were, therefore, separately determined from the Season and Crop Reports published by the Director of Land Records, Punjab. Similar data for weather conditions was also collected for the three districts. The yields of one big commerical farm located in each of the three districts were also collected as the conditions of cultivation were assumed to be more uniform on these farms than those prevalent in the districts.

(*i*) SECULAR TRENDS IN YIELDS.

The secular trends in the mean values of yields for the three farms and the three districts were studied by employing the Fishers' method of polynomial curves (1924). The analysis of variance for the yields of Americans from 1921—1940 for the three districts are given below:

Table LIX.

Analysis of variance—Mean square.

Due to	D.F.	Lyallpur.	Montgomery.	Multan.	Brucepur Farm.	Okara Farm.	B.C.G.A. Farm.	Punjab.
Average rate of change	1	32.5687	18.8460	38.0024	75.5005	13.9712	7.8159	21.0571
Secular trends ..	4	7.6669	8.4001	6.0945	4.4403	8.6154	29.5041	4.4316
Residual	14	0.8233	1.5134	0.7683	3.0155	3.1139	7.1073	0.8900

There was a definite indication that the cotton yields in three districts and the two farms had materially changed. The high rate of change may be due to the introduction of new varieties like L.S.S., 289F/43 and 289F/K25 in place of 4F but there was no evidence to support this assumption.

The secular variations in mean yields of Americans for the three districts and the three farms can be seen from Table LX.

Table LX.

Yields of Americans in mds. p. a.

	Lyallpur.	Montgomery.	Multan.	Brucepur Farm.	Military Farm, Okara.	B.C.G.A. Farm.	Punjab.
Mean	6.63	5.60	5.33	7.94	7.08	9.98	5.74
S.D. . . .	1.98	1.97	1.97	2.67	2.20	3.44	1.64
C.V.	30.0	32.8	36.9	33.6	31.1	34.5	28.6
×'2	+5.71	+4.34	+6.17	+8.69	+3.74	−2.80	+4.59
×'3	+0.62	−1.46	+1.49	+0.47	−2.87	+1.19	+0.83
×'4	−1.24	−3.49	−2.15	−3.38	−2.08	+0.73	−1.69
×'5	−3.55	−2.66	−2.08	−2.42	−1.04	−1.93	−2.64
×'6	+4.02	+3.50	+3.66	..	+4.03	+10.60	+2.69
S. Residue	0.91	1.23	0.87	1.68	1.77	2.67	0.94
No. of years	20	20	20	20	20	20	20

Table LXI.

Correlation coefficients between yields and weather factors (Lyallpur 1921-1935).

Period.	A. Without eliminating secular changes.				B. After eliminating secular changes.			
	Jan-April.	May-June.	July-Aug.	Sept.-Oct.	Jan.-April	May-June.	July-Aug.	Sept.-Oct.
Average range of temperature ..	−0.4998	−0.0541	+0.1085	+0.1821	−0.1634	−0.1286	−0.0476	−0.1707
Mean of maximum and minimum temp. $\frac{M+m}{2}$ ..	−0.5227*	−0.5386*	−0.1495	−0.1550	−0.2378	−0.5286	−0.1508	−0.0839
Average humidity	+0.5446*	+0.1475	+0.1724	−0.3328	+0.1996	+0.7241*	+0.4123	+0.2750
Total Rainfall ..	+0.5403*	+0.1759	−0.0925	−0.4235	+0.3007	+0.3565	+0.3292	−0.4601

The coefficient of variability was of the same order in the districts as well as the farms, Multan district giving the highest value. The similarity in the slow changes in mean values of yields can be seen from the significant positive nature of $\times'^{6}$ and the significant negative nature of $\times'^{5}$.

After the secular changes had been eliminated, the remaining variations in yields could be attributed to the weather conditions. It was, therefore, necessary to eliminate the secular trends from the yield series before the correlation of weather factors with yields could be studied. It was also thought of interest to determine the correlation coefficients between yields and weather factors without eliminating secular changes.

(*ii*) Correlation Studies between Yields and Weather Factors.

The secular trends were also found to occur in temperature, humidity and rainfall at Lyallpur and they must also be eliminated. For the purpose of this study the cotton season was divided into three periods: early (May-June), middle (July-August) and the end (September-October) period.

Simple correlation coefficients between yields and average range of temperature, mean of maximum and minimum temperature, average humidity and rainfall were first determined for Lyallpur. The results obtained were complex and gave no clue regarding the effect of any weather factor on yields (Table LXI). There were two instances where the correlation coefficients between average humidity for May-June period and yields after eliminating secular trends, and between $\frac{M+m}{2}$ temperature and yields for the same period were significant.

As the values of correlation coefficients between yields and the two weather factors for the period May-June were high it was necessary to study their combined effect on yields. This was done by fitting a regression equation and finding out partial regression coefficients. They were however found to be non-significant as shown below:—

Table LXII.

Partial regression coefficients with standard errors for Lyallpur.

Average temperature $\frac{M+m}{2}$	$= -0.3917 \pm 0.3297$
Humidity	$= +0.1857 \pm 0.1246$
Rainfall	$= +0.0204 \pm 0.7008$

For further details the paper by Dastur and Tashna (1943) may be consulted.

The magnitude of yield was governed by the morphological characters, the number of bolls and the weight of bolls, *i.e.* weight of seed cotton per boll. In the Punjab, unlike other cotton growing tracts, the boll weight was found to vary greatly on account of the prevalence of *tirak* which however did not affect the boll number. The weather factors that affected the boll number might not affect the boll weight and *vice versa*. *Tirak* also occurred on two different soil types and the weather factors that may increase the incidence of *tirak* on one soil type may be different from the weather factors that affected the incidence of *tirak* on the other type of soil. It was, therefore, not surprising to find absence of significant correla-

tionship between the weather factors and yields. A study of the weather factors that were causing widespread occurrence of *tirak* in failure years was, therefore, undertaken.

(*iii*) The Effect of Temperature on the Spread of *Tirak*.

An indication of the nature of the weather factors that increased the incidence of *tirak* and caused it to appear on larger areas than normal on soils which contained free soluble sodium salts in the subsoil was given by observations made on the crop in the same fields, from year to year. It was shown in Chapter IV that salinity in the subsoil varied from field to field and even in the different parts of the same field measuring an acre. It was also pointed out in the same chapter that the effect of salinity in the subsoil on the development of *tirak* varied as other soil conditions like the total concentrations of free salts, the physical texture and the calcium ; sodium ratio either in soluble or exchangeable form varied. The intensity of *tirak* thus varied in the same year as the soil complex varied from field to field. In 1939 it was observed that the intensity and the spread of *tirak* had greatly increased in the different fields which were under observation. *Tirak* appeared in a more intense form in all these fields than was the case in previous years. *Tirak* was also found to spread to those parts of the fields where usually normal crop was found. The investigations of the soil conditions in these new regions of the fields where *tirak* newly appeared showed that the subsoils contained smaller amounts of free soluble or exchangeable sodium. The *tirak* promoting conditions in such areas were less intense than in other areas where *tirak* occurred every year.

The cotton crop in 1939 was quite normal up till September but later *tirak* symptoms began to appear and the change from normal to *tirak* condition became rapid; so much so, that in October almost the enitre crop in each of these fields showed *tirak* symptoms. It was, therefore, evident that some peculiarity of weather conditions was associated with the greater spread of *tirak* in that year.

The crops exhibited signs of desiccation resulting in premature defoliation. It was evident that the water balance of the plant was greatly disturbed. The bolls ceased to grow and opened in that immature state. Wherever the soils were light sandy and highly saline in the subsoil the damage to the crop was great, while wherever the soils were of low salinity and less sandy the damage was found to be less.

A study of the weather data for 1939 revealed that the months of September, October (Fig. 29) and the first half of November were characterised with spells of hot and dry weather extending from 10 to 15 days. The maximum temperatures during these spells were above the normal maximum temperatures. These months were also dry. The spells of hot weather increased the water deficit of the crop on the soils with highly saline subsoils and caused an intensification of *tirak* on such lands. In addition, a disturbance in the water balance of the crop also occurred on soils with low salinity during these spells of hot weather and *tirak* symptoms appeared on such lands where the salinity was low and where *tirak* did not develop in other years. Thus hot and dry weather during the fruiting period produced *tirak* in American cottons on more extensive areas than was normally the case and a partial failure of cottons occurred in 1939. In the good crop years such as 1935 (Fig. 29) no such spells of higher temperatures than normal were found to occur.

If the above explanation of the partial failure years of American cottons in the Punjab was correct, similar spells of hot weather in fruiting months must have occurred in the previous failure years on record. The weather data for the months

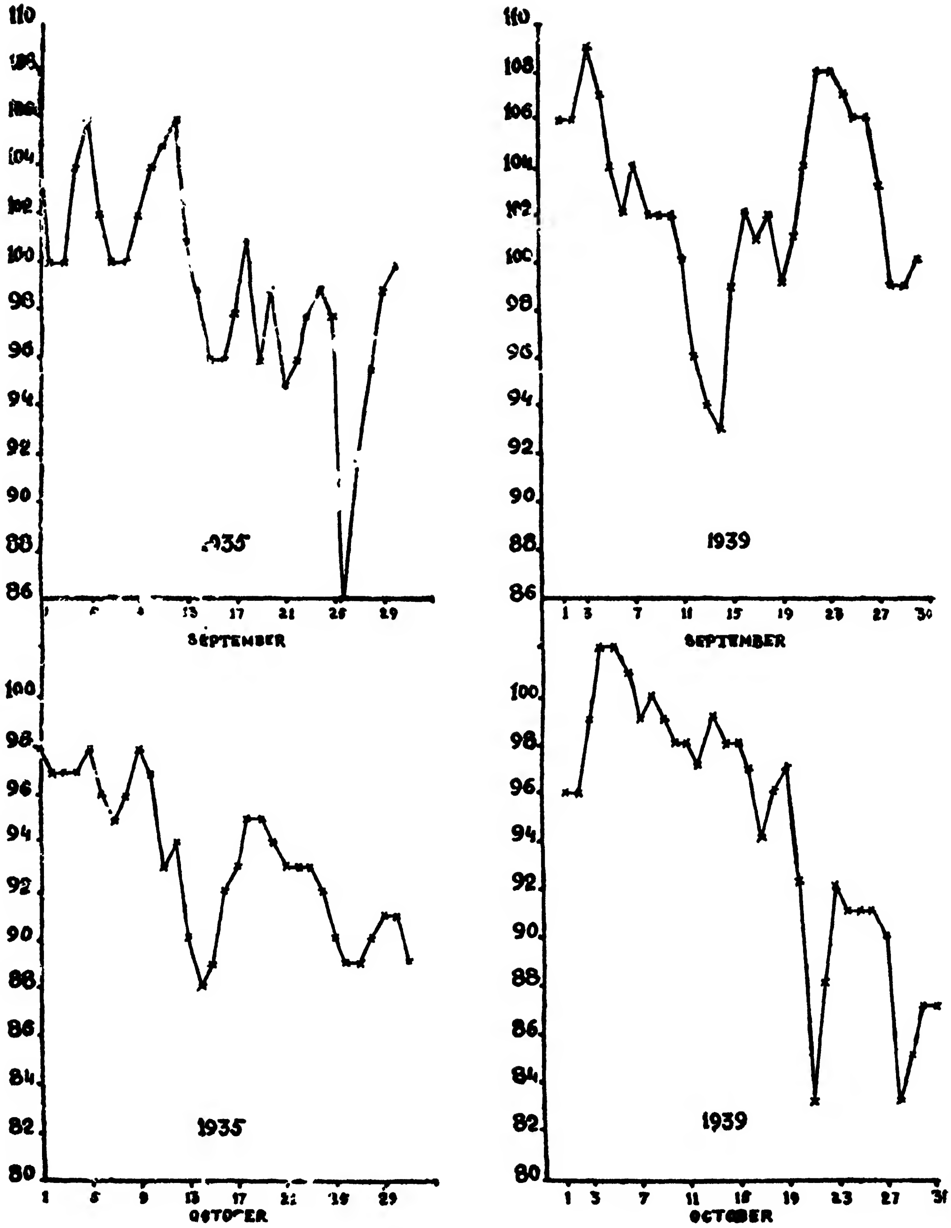

FIG. 29.—The daily maximum temperatures in the months of September and October showing the spells of higher temperatures than normal in 1939 (*tirak* year) and their absence in 1935 (good year).

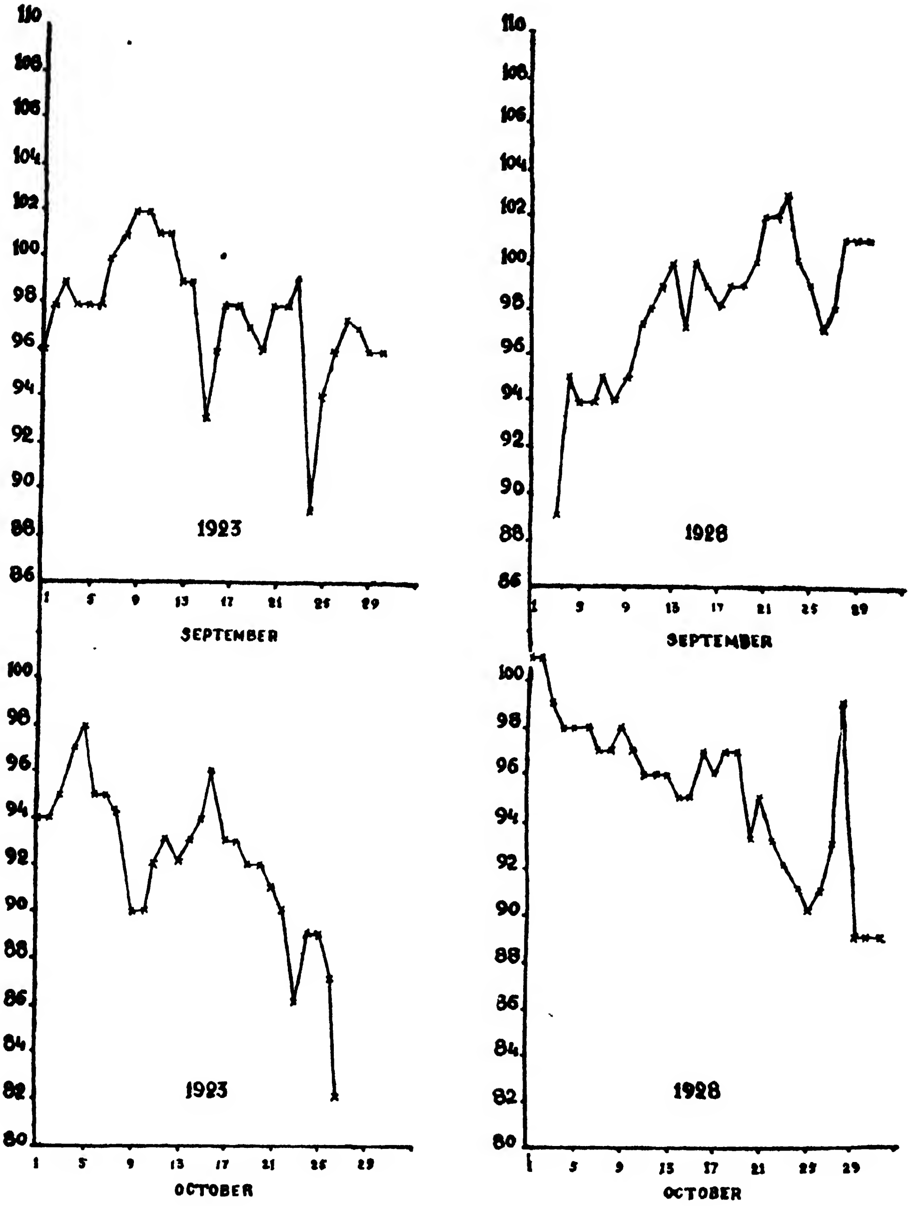

FIG. 30.—The daily maximum temperatures in the months of September and October in the partial *tirak* year (1928) and good year (1923) showing the presence and absence of spells of higher maximum temperatures than normal.

of September and October were, therefore, studied and it appeared that similar spells of higher temperatures than normal had occurred in the majority of the past failure years (Fig. 30). In some failure years the monthly means of maximum temperatures also came out to be higher by 2° to 5° F. than the normal monthly means (average of 10 years) on account of the occurrence of hot spells in the two months but in other failure years that was not found to be the case. In such years either the spell of hot weather was followed by days of very low temperatures or the spell of hot weather started towards the end of September and extended into the month of October. Consequently, the monthly means of maximum temperatures came out to be normal or even below normal in some cases.

In Table LXIII the departures of the monthly means of maximum temperatures from the normal monthly means of maximum temperatures and the number of days when the temperatures were above normal for Multan and Lyallpur are given for good years and for *tirak* years. Partial *tirak* years are indicated by an asterisk. It will be seen that the characteristic of *tirak* years was either unusually warm September or warm October. The monthly means of maximum temperatures in some *tirak* years were above normal by 2° to 4° F. There were, however, *tirak* years when the monthly means were not above normal. 1926 was a *tirak* year. The monthly mean of maximum temperature in October was higher than normal by 1.7° F. at Multan but not at Lyallpur. Similarly the monthly mean of maximum temperature in September was above normal by 3.6° F. at Lyallpur but it was not so at Multan in the partial *tirak* year of 1937. The day-to-day study of temperatures, however, showed that the hot spells had occurred in these years in the two districts but the monthly means of maximum temperatures did not come out above normal on account of reasons explained above. The intensity and the spread of *tirak* were also found to vary from district to district in the same *tirak* year on account of the differences in the spells of hot weather in the fruiting months in different districts.

TABLE LXIII.

	MULTAN.				LYALLPUR.			
	Departures from normal monthly means of max. temperature of		No. of days when max. temperatures were above normal.		Departures from normal monthly means of max. temperatures of		No. of days when max. temperatures were above normal.	
	Sept.	Oct.	Sept.	Oct.	Sept.	Oct.	Sept.	Oct.
Tirak years.								
1926	—1.4	+1.7	11	23	—2.3	+0.8	10	16
1927	+2 0	+3.3	21	30	+2.1	+1.6	26	24
1928	+0.4	+3.7	15	28	—0.6	+2.7	18	24
1932*	+4.2	+1.3	29	20	+4.1	+1.8	25	20
1937*	+0.9	—1.5	20	14	+3.6	+0.4	27	18
1938*	+0.6	+0.8	13	21	+3.6	+1.8	26	20
1939	+3.6	—0.2	22	22	+5.0	+1.4	27	19
1940*	—1.2	+1.0	9	25	+0.7	+2.7	19	29
1941*	—1.9	+4.0	12	29	—1.5	+3.8	14	26
Good years.								
1923	—1.2	—2.8	8	17	—0.3	—2.6	18	14
1924	—4.6	—0.1	1	17	—3.5	+0.4	3	14
1933	—2.2	—0.2	9	18	—3.5	+0.6	7	18
1935	—0.0	—2.6	14	9	+1.5	+1.9	18	22
1936	—2.0	+0.2	8	21	+1.9	+0.6	22	19

(iv) Correlation between Yields and Temperatures in the Fruiting Period.

As there was a clear indication that *tirak* years were characterised by spells of hot weather in the fruiting period, it was necessary to see if there was any correlation between yields and maximum temperatures. The correlation coefficients were worked out in two ways: (1) The correlation coefficients between yields and the maximum temperatures of each fortnight beginning from 1st September up to 31st October were determined, (2) the correlation coefficients between yields and the degrees above the normal monthly mean of maximum temperatures in a spell of eight days or more in September and October were also determined. Two periods were taken : 1921—1940 for which the yields of Americans per acre were available and 1914—1940 for which the yields of Americans and *desis* together were available. Prior to 1921 American and *desi* yields were not separately recorded. The correlation coefficients were determined separately for the three districts and for the three commercial farms located in these districts.

The results of the correlation coefficients between yields and maximum temperatures for each fortnight in the months of September and October are given in Table LXIV. It will be seen that in the majority of cases there was a negative correlation between yields and maximum temperatures and in the remaining cases there was a positive correlation coefficient.

When the correlation coefficients between yields and maximum temperatures for September and October taken together were determined, similar complex results were obtained.

Table LXIV.

Correlation coefficients between maximum temperatures and yields.

	American yields 1921—1940.				American + *desi* yields 1914-1940.			
	1st half Sept.	2nd half Sept.	1st half Oct.	2nd half Oct.	1st half Sept.	2nd half Sept.	1st half Oct.	2nd half Oct.
Lyallpur	+.1327	—0.0992	+.1911	—.0310	—.1083	—.3876*	—.2270	—.0391
Montgomery ..	—.2836	— .1707	—.2031	—.0456	—.0120	—.2813	—.3342	—.0267
Multan	—.4187	— .4572	—.0653	+.3493	—.2195	—.2240	—.2198	+.0165
Brucepur farm ..	+.5891*	— .1417	—.0228	—.8899**	..	..	..	..
Millitary farm ..	—.1144	— .1761	—.4482	—.3356	..	..	..	..
B.C.G.A. farm ..	—.3726	— .2557	+.1667	—.3274	..	..	..	..

Similar results were obtained when the yields of Americans and *desis* were taken together for the period 1914—1940. It may, however, be pointed out that in most of the cases the values of correlation coefficients between yields and maximum temperatures were negative, suggesting that yields were adversely affected by high maximum temperatures.

The correlation coefficients for monthly rainfalls and yields for Americans were determined for 1921—1940 and the results were again complex. In Multan district the correlation coefficients between monthly rainfall and yields were positive for all the four months but that was not the case in other districts.

When the spells of higher maximum temperatures than normal were taken for this study of exploring the relation between temperatures and yields, it was

possible to obtain good evidence that hot weather in the months of September and October was related to low yields of cotton. For this study the degrees above the normal maximum temperatures (average of 10 years) in a spell lasting for 8 days or more were taken. It was assumed that a hot spell lasting for eight days in these two months was long enough to cause damage to the crop. It was, however, to be expected that a continuous spell of 16 days did more damage than two separate spells of eight days each separated by a period of normal temperatures. As a study of this relationship was considered important the correlation coefficients were determined with and without eliminating time trends (secular changes).

TABLE LXV.

	Americans only. 1921—1940.		Americans + *desis*.	
	Time trends not eliminated.	Time trends eliminated.	Time trends not eliminated.	Time trends eliminated.
Lyallpur	—0.4493	—0.1036	—0.2635	—0.2655
Montgomery	—0.4776*	—0.4105	—0.3266	—0.4126**
Multan	—0.7211**	—0.4088	—0.5776**	—0.5566**
Brucepur Farm	—0.1155	—0.2256	..	..
Okara ,, ...	—0.4958*	—0.4535	..	..
B.C.G.A. ,, ...	—0.5616*	—0.3985	..	..

The results (Table LXV) showed one common feature *viz.* the values of the correlation coefficients were negative in all cases. Thus there was a definite indication of a fall in yield as the degrees above the normal maximum temperatures in the hot spells in the two months increased. The values of correlation coefficients increased from Lyallpur to Multan tract. This result indicated that high temperatures affected the yields more in Montgomery and Multan districts than in Lyallpur district. The normal maximum temperatures are generally higher in the former districts than in the latter. The adverse effect of hot spells in these two months on *tirak*, and consequently the yields, were therefore higher in Multan and Montgomery districts than in Lyallpur district. The correlation coefficients between the degrees above the normal maximum temperatures in hot spells and yields of the three farms located in three districts were also negative and the values of coefficients were lower at Brucepur (Lyallpur Dist.) than at the two remaining places.

It is clear, therefore, that the nature of weather factors that caused widespread *tirak* in the failure years could only be studied in terms of the spells of hot weather. The monthly or the fortnightly means of maximum temperatures may be misleading for, the influence of spells of unusually high temperatures may not figure in the averages due to very low temperatures in other days of the month. The prominence of a heat spell can also be obliterated in the monthly means, as the spell may start

at the close of a month and extend into the next. On the other hand, the damage done to the crop during the hot spells may not be repaired by spells of low temperatures during the same month.

Numerous attempts have been made in the past to correlate the variations in the yields of seed cotton with weather conditions and other geographical factors. Those of Smith (1925), Hale (1933) and Fulton (1939) in America, and Kalamkar *et al.* (1935) in India, and Crowther and Crowther (1935) in the Sudan, deserve special mention. This investigation has brought in two new features in such a study. The study of the effect of weather conditions in relation to soil conditions on yields has not been attempted before. Similarly the spells of high temperatures above the normal are of greater importance in such a study than the monthly, fortnightly or weekly means of maximum temperatures.

Salinity in the subsoil in the cotton soils of the irrigated tracts of the Punjab has been found to be a widely spread feature. Its concentration was also found to vary both vertically and horizontally. There were patches of soil where *tirak* occurred every year though it varied in intensity year to year. *Tirak* spread to soils with less salinity when the months of September and October were unusually dry and warm. *Tirak* in such seasons became widespread and intense and general failures were caused. The magnitude of the damage caused to the crops when the weather in the fruiting period was unusually dry and warm could be seen from the fall in yields registered in two fields with a saline subsoil in 1939 as compared with the yields in other years when *tirak* was less intense and was confined to patches which had highly saline subsoil. The relative intensity of *tirak* in different years could also be seen from the average weights of seed cotton per boll.

TABLE LXVI.

Year.	Field I.					Field II.		
	1936.	1938.	1939.	1940.	1941.	1937.	1939.	1940.
Yields in mds. per acre ..	14.50	15.48	*4.78*	13.53	18.3	16.00	*10.09*	17.7
Wt. of seed cotton per boll in gm. ..	..	1.88	*0.77*	1.70	2.70	1.98	*1.15*	2.01

The failure years were thus caused as a result of weather conditions reacting with certain soil conditions.

Though the interaction of temperature with the subsoil salinity in the intensification and the spread of *tirak* has been demonstrated, the relation of weather conditions that may be aggravating *tirak* caused by nitrogen deficiency on light sandy soils remains to be explained. During the *tirak* year of 1939, *tirak* was found to be more intense on light sandy soils than in any one of the previous years under observation. There was a definite decrease in the boll weight in such fields as compared with the boll weights recorded in the previous seasons. It is probable that on such lands the factor of physical drought came into operation and further decreased the seed maturity in addition to the immaturity of seeds already occurring on such soils on account of the indirect effect of a deficiency of nitrogen as already explained in Chapter VII.

CHAPTER XII.

'BAD OPENING' OF BOLLS IN SIND-AMERICAN COTTONS IN SIND

(*i*) General.

With the introduction of perennial irrigation in Sind after the construction of Lloyd Barrage in 1932, the acreage under American cotton crop in Sind had considerably increased so much so that out of a total of 844,597 acres under cotton in 1946-47 the area under American cottons was 740,139 acres. Nearly 90% of the total cotton crop in Sind was, therefore, American. The cotton area in Sind can be divided into three tracts on account of small differences in the climatic conditions prevailing in each; (1) South and East tract comprising of Tharparkar and lower half of the Hyderabad district; (2) Middle Sind comprising of Nawabshah district; and (3) North Sind comprising of Larkana district and some parts of Sukkar district. Of the three tracts, the first two are situated on the left bank of the Indus river, while the third tract is on the right bank. The first was by far the most important cotton tract where major portion of the total American cotton crop was grown.

There are small but important differences in the climatic conditions in these tracts. South and East Sind are characterised by a milder climate than Middle and North Sind. In South and East Sind the temperatures are as high as in Middle or North Sind during the months of April and May but they drop appreciably towards the end of June in South Eastern parts as compared with the temperatures prevailing in other two tracts where high temperatures continue to prevail uptil September. The relative humidity at day is also higher during the growing period in the South and East Sind than in Middle and North Sind. Climatically the South and East Sind was therefore different from the other two zones, the latter resembling in climatic conditions the south-western tracts of the Punjab. The differences in climatic conditions in the three cotton growing areas of Sind were responsible for the differences in the sowing and harvesting time for the cotton crop. The crop was planted and harvested in the South and East Sind earlier than in the Middle and North Sind or in the Punjab. The climatic conditions in North Sind were still more severe than in the Middle Sind.

Various exotic varieties of cotton, American, African and Egyptian, were imported and tried in Sind since last about 100 years *i.e.* much before the opening of the Jamrao Canal System in East Sind in 1900, but these attempts met with little success. The Punjab-American varieties were then imported in Sind in 1923-24 and various selections were made of which 4F/98 and Sind Sudhar proved to be suitable for growing in Sind. These strains were given to the cultivators in 1933-34 and the acreage under these strains increased every year since then, with a consequent reduction in acreage under the *desi* types. Later on, another strain named M4 was produced at Mirpurkhas by pure line selection, from another Punjab-American strain called N. T. 21 and it entered into large scale cultivation in the year 1940. This strain was earlier in maturity, gave higher yield and lint out-turn but was coarser than Sind Sudhar.

M4 has now become a popular strain with the cotton growers in Sind and has almost replaced Sind Sudhar. Another Punjab-American variety L.S.S. was also grown in Eastern parts of Sind and at one time was very popular with some cotton growers. It was, however, going out of cultivation as it was a late maturing variety and was found to suffer greatly from the red leaf disease.

The American cotton crop in Sind has been reported to suffer from two types of physiological diseases ever since it entered into large scale cultivation. These were 'bad opening' of bolls and the red leaf blight. The 'bad opening' of bolls indicated the prevalence of *tirak* as in the case of Punjab-American cottons though the periodic failures of American cottons accompanied by intensification and spread of *tirak* as in the Punjab have not been reported from Sind. The 'bad opening' of bolls has only been reported in the year 1932 by Barakzai (1938) in his report of Sind Physiological Scheme which was partly financed by the Indian Central Cotton Committee. It will be shown below that the climatic conditions prevailing in Southern and Eastern parts of Sind which constituted the major portion of American cotton growing tract were not favourable for the general spread of *tirak* which in this tract was only confined to permanent patches of soils with high salinity. The climatic conditions in Middle and North Sind are similar to those in Punjab and the 'bad opening' of bolls was aggravated in certain years but as the acreage under American cottons in this tract forms a very small proportion of the total acreage in Sind, failure of cotton crop as a whole had not taken place in the past.

The red leaf blight in Sind-American cottons has been of very frequent occurrence. It is reported almost every season in the months of September-October though its intensity and spread may vary from year to year. No specific mention of particular years as red leaf blight years has been made. It appeared from observations made on the crop during the period 1942 to 1946 that leaf reddening was a common phenomenon and it was very widespread in the Southern and Eastern cotton zones of Sind. Though there was no experimental evidence of the lowering of yield as a result of red leaf blight, it was believed that such lowering of yield was caused by this disease.

It was, therefore, undertaken to investigate the causes that produced the symptoms of 'bad opening' of bolls and the red leaf disease in American cotton grown in Sind and to remedy them if possible. A scheme financed jointly by the Indian Central Cotton Committee and Sind Government was sanctioned in 1943 for a period of three years and the results obtained are briefly discussed here. In this Chapter the causes and the amelioration of 'bad opening' of bolls in Sind-American cottons are discussed and in the next Chapter the causes and remedies for the red leaf disease are summarised.

(*ii*) THE TWO SOIL TYPES ASSOCIATED WITH 'BAD OPENING' OF BOLLS.

During the cotton season of 1942 several fields were noticed in the different parts of Sind where the American cottons showed symptoms of 'bad opening' of bolls which contained immature seeds with poor quality of lint. The drooping and shedding of leaves in some fields were found to have been associated with 'bad opening' of bolls. These symptoms resembled *tirak* symptoms described for Punjab-American cottons in the Punjab on soils with saline sub-soil. The yellowing and shedding of leaves was also a feature of Sind-American cottons in Sind and these symptoms indicated light sandy lands deficient in nitrogen. It was, therefore, undertaken to determine if the same two soil types, *viz.* (1) Soils with saline soils and (2) Light sandy lands deficient in nitrogen were associated with 'bad opening' of bolls in Sind as was found to be the case in the Punjab.

Analysis of the soil upto a depth of six feet from fields, where drooping and shedding of leaves accompanied by 'bad opening' of bolls was found to occur in different cotton tracts, was made and it was found that such fields contained abnormal quantities of soluble sodium salts in the sub-soils as was the case in the Punjab. Results of soil analysis for two places are given below in Table LXVII.

TABLE LXVII.

Soils with saline sub-soil.

Depth in feet.	Nasirabad Estate (Kinjhejhi).						Cotton Botanist Farm (Mirpurkhas).					
	Total salts. %	Soluble calcium. %	Soluble sodium %	Exchange-calcium. m.e.	Exchange-able Na + K. m.e.	pH.	Total salts. %	Soluble calcium. %	Soluble sodium. %	Exchange-able calcium. m.e.	Exchange-able Na + K m.e.	pH.
1st foot ..	0.063	0.011	0.006	10.8	1.4	8.3	0.080	0.013	0.006	8.4	0.8	8.1
2nd " ..	0.096	0.015	0.014	11.6	1.4	8.2	0.256	0.024	0.048	7.6	1.4	8.0
3rd " ..	0.162	0.023	0.033	10.8	1.6	8.1	0.454	0.025	0.146	6.0	0.4	8.0
4th " ..	0.174	0.022	0.033	9.2	1.2	8.1	0.435	0.015	0.122	4.8	2.6	8.3
5th " ..	0.330	0.031	0.046	6.4	1.0	8.0	0.497	0.017	0.132	4.4	3.2	8.2
6th " ..	0.554	0.051	0.088	8.8	1.8	7.9	0.537	0.017	0.136	4.8	2.8	8.2

Soluble sodium was found to be higher than soluble calcium while exchangeable sodium was present in some cases but not in others. Similar results were obtained from the analysis of the soil samples taken from fields where *tirak* had occurred in other parts of Sind.

Light sandy soils were found to be widely distributed in Sind. In chemical and physical properties they resembled the light sandy lands met with in the Punjab (*vide* chapter IV). In many cases the clay was lower than 10%. Such light sandy soils were found to contain normal quantities of soluble salts in some cases while in some cases they were found to contain abnormal amounts of sodium salts. Thus both *tirak* promoting conditions were also found associated together as in the Punjab.

TABLE LXVIII.

Light sandy soils with normal sub-soils.

DENISAR ESTATE—(EAST SIND)

Depth. in ft.	Total salts. %	Soluble calcium. %	Soluble sodium. %	Clay. %	Silt. %	Sand. %
1st ft.	0.063	0.010	0.008	7	14	76
2nd „	0.060	0.010	0.007	11	17	72
3rd „	0.068	0.009	0.005	9	26	64
4th „	0.066	0.013	0.007	9	34	56
5th „	0.093	0.014	0.007	15	39	45
6th „	0.080	0.014	0.006	23	54	22

The crop on light sandy land showed premature yellowing and reddening of the leaves in the months of August and September. The red leaf blight generally developed on such lands and the investigations on this physiological disease will be dealt with in the next Chapter.

In addition to the abovementioned soil types found in Sind there were soils which contained a very high proportion of clay varying from 30 to 50% of the total in different layers. Such soils were not found suitable for cotton growth as the crop remained small and stunted. These soils were also found unsaturated with bases.

(*iii*) AMELIORATION OF 'BAD OPENING' BY DELAYING SOWINGS.

As late sowing was found to be a common remedy for *tirak* occurring on both soil types in the Punjab, it was undertaken to try out this measure to ameliorate 'bad opening' of bolls occurring in Sind-American cottons in Sind. It was necessary to arrange experiments on the two soil types in the different parts of Sind as the normal sowing period for cottons differed in the three different tracts. It was decided to go beyond the normal sowing period by one month or more to determine the remedial effect of late sowing on the 'bad opening' of bolls as compared with the 'bad opening' occurring in the normally sown crop. Three to four sowing dates were, therefore, included as treatments in each experiment. M4, L.S.S. and Sind Sudhar were the three varieties normally grown in Sind and these were included in the experiments. In addition, the different Punjab-American cottons like 289F/K25,

289F/124 and 289F/199 were also included in some of these experiments. In some experiments laid out on light sandy lands the application of sulphate of ammonia was included as a separate treatment besides the late sowing, to study, the remedial effect on 'bad opening' of bolls of the application of sulphate of ammonia to light sandy lands. The effect of application of an extra irrigation during fruiting period to heavy sandy loams with saline sub-soils on 'bad opening' of bolls was also studied in some experiments in view of the results obtained in the Punjab. All experiments were designed employing modern technique as was done in the Punjab. The details of each experiment conducted in Sind are not given to economise space. The experiments were conducted during the period 1943 to 1946. The boll weight determinations were made from randomised plants in each sub-plot of all the replicates at each picking and the results were statistically analysed. The boll weight determinations were made in 16 such experiments and the results of some of these experiments are given below in Table LXIX. The results obtained again confirmed the findings in the Punjab. Late sowing was found to decrease 'bad opening' on both the soil types and in all varieties experimented upon. There was in all experiments an increase in weight of kapas per boll as the sowing time advanced indicating better maturity.

Cotton sowings in South and East Sind normally began by the third week of March and terminated by the end of April. So May and early June sowings along with March and April sowings were also included in the experiments conducted in this tract. It was found that later sowings gave significantly higher boll weight than the normal sowings (Table LXIX), both at Kinjhejhi and Denisar Estate which were situated in South-Eastern parts of Sind. M4 strain gave significantly higher boll weight than Sind Sudhar or L.S.S.

The normal sowing period for the middle Sind was between the middle of May and the middle of June, so late June and July sowings were included along with normal sowings in the experiments conducted in that tract. The results obtained in the two of the sowing date experiments conducted at Sakrand and at Pad Idan in this tract are given in the Table LXIX. The end-June and July sowings gave significantly higher boll weights than the first two sowing at Sakrand. Similarly at Pad Idan the first two sowings suffered more from 'bad opening' of the bolls than the last two sowings.

(*iv*) Amelioration of 'bad opening' by application of nitrogen.

The effect of the application of nitrogen fertilizers on light sandy lands on the opening of bolls was studied in some of the experiments and it was found that manured plants produced better maturity of seeds than the unmanured plants.

Table LXIX.

The remedial effect of late sowing on 'bad opening' of bolls as determined by the increase in weight of seed cotton per boll in gm.

Variety.	Experiment No. 7 Kinjheji (1943)					Variety.	Experiment No. 2 Denisar Estate (1943)				
	Sowing dates						Sowing dates				
	29th March	19th April	9th May	30th May	Mean (±0.048)		2nd April	23rd April	16th May	3rd June	Mean (±0.041)
M4 ..	2.45	2.84	3.25	3.71	*3.06*	M4	2.43	2.86	3.30	3.55	*3.04*
Sind Sudhar ..	1.72	2.11	2.05	2.79	*2.17*	Sind Sudhar	2.57	2.74	3.15	3.25	*2.93*
L. S. S. ..	2.24	2.39	2.49	2.92	*2.51*	L. S. S. ..	2.59	2.72	2.88	2.89	*2.77*
Mean (±0.062)	*2.14*	*2.45*	*2.60*	*3.14*		Mean (±0.072)	*2.53*	*2.77*	*3.11*	*3.23*	

Variety.	Experiment No. 24 Sakrand (1943) Sowing dates					Variety.	Experiment No. 32 Pad Idan (1946) Sowing dates				
	14th May	3rd June	24th June	17th July	Mean		22nd May	7th June	22nd June	7th July	Mean (±0.05)
M4	2.71	2.77	3.07	2.77	*2.83*	M4	2.10	2.16	2.26	2.38	2.22
Sind Sudhar ..	2.20	2.22	2.33	2.71	*2.37*	Sind Sudhar ..	1.24	1.62	1.80	*1.99*	1.66
289F/K25 ..	2.72	2.61	2.98	2.82	*2.78*						
289F/124 ..	2.67	2.52	3.11	2.97	2.82						
Mean (±0.11)	*2.57*	*2.53*	*2.87*	*2.82*		Mean (±0.11)	*1.67*	*1.89*	*2.03*	*2 18*	

The results of boll weight are given for the experiments conducted at Denisar Estate, Hyderabad and Sakrand in the following Table LXX.

TABLE LXX.

The remedial effect of the application of sulphate of ammonia on 'bad opening' of bolls.

	Experiment No. 4 Denisar Estate (1944).		Experiment No. 18 Hyderabad (1944).		Experiment No. 26 Sakrand (1944)	
	Control.	*Manured.*	*Control.*	*Manured.*	*Control.*	*Manured.*
M4	2.42	2.60	3.17	3.26	2.83	3.06
L. S. S.	2.28	2.40	2.55	2.80	2.13	2.49
Sind Sudhar	2.06	2.14	2.52	2.72	2.22	2.65
Mean	*2.25*	*2.38*	*2.75*	*2.93*	*2.40*	*2.73*
S. E.	(+0.06)		(±0.03)		(±0.06)	

There was a significant increase in boll weight as a result of application of sulphate of ammonia indicating better maturity of seeds in the manured plots. It may be mentioned that 'bad opening' was generally more pronounced on soils with saline sub-soils than on light sandy lands. As two sowing dates were included in the above experiments the results for the control and manured plots were an average of two sowing dates and consequently the ameliorative effect of later sowing has increased the boll weight in the control plots. If the results of control and manured plots of the first sowing are studied separately, the differences between the boll weights under two treatments would be still greater.

(*v*) RESULTS OF ALL EXPERIEMENTS ON AMELIORATION OF 'BAD OPENING.'

The results of the mean weights of seed cotton per boll in gm. under different sowing dates averaged over all other treatments along with standard errors for the 16 complex experiments conducted from 1943 to 1946 are given in the following Table LXXI. A study of the results will show that there was a progressive increase in the weight of seed cotton per boll as the sowing was done later in each tract of Sind indicating 'better opening' of bolls. In Experiment No. 19 conducted at Hyderabad the boll weights under all the four sowing dates were nearly the same indicating normal opening under all sowings.

TABLE LXXI.

Mean weight of seed cotton per boll in gm. under different sowing dates.

Expt. No.	Place	Year	Sowing dates				S. E.
2	Denisar Estate	1943	2nd April 2.53	23rd April 2.77	16th May 3.11	3rd June 3.23	±0.072
3	„ ..	1944	25th March 1.60	15th April 1.89	4th May 1.95	25th May 2.04	±0.068
4	„	1944		18th April 2.21		22nd May 2.42	±0.061
6	„	1946	1st April 2.28	15th April 2.40	30th April 2.51	15th May 2.69	±0.068
7	Kinjhejhi	1943	29th March 2.14	19th April 2.45	9th May 2.60	30th May 3.14	±0.062
8	„	1944	8th April 2.38	26th April 2.64	15th May 2.79	3rd June 2.92	±0.076
12	Mirpurkhas	1943	9th April 1.73	30th April 2.10	20th May 2.90	10th June 3.23	±0.074
18	Hyderabad	1944		22nd April 2.70		22nd May 2.98	±0.035
19	„	1944	17th April 2.94	7th May 2.85	3rd June 2.86	24th June 2.90	
20	„	1945		30th April 2.84	21st May 3.04	11th June 3.68	
21	„	1946	15th April 2.56	30th April 2.67	15th May 2.71	30th May 2.85	±0.069
24	Sakrand	1943	14th May 2.57	3rd June 2.53	24th June 2.87	17th July 2.82	±0.11
25	„	1943	22nd May 2.85	10th June 3.28	3rd July 3.39	22nd July 3.26	
26	„	1944		25th May 2.44		25th June 2.69	±0.068
29	„	1946	18th May 2.25	3rd June 2.45	22nd June 2.45	8th July 3.01	
32	Pad Idan	1946	22nd May 1.67	7th June 1.89	22nd June 2.03	7th July 2.18	±0.11

(VI) THE EFFECT OF LATE SOWING IN COMBINATION WITH CLOSER SPACING ON YIELD.

Late sowing was thus found to ameliorate 'bad opening' of bolls on both the soil types in Sind American cottons in Sind. It was also observed that the yellowing and reddening of the leaves on light sandy lands did not occur at all or occurred to a lesser extent in crop sown later than the normal time. It was, therefore, necessary to study how far and to what extent this measure of late sowing can be put into actual practice. It was shown in the investigations conducted in the Punjab that late sown crops suffered from a serious disadvantage of a reduction in bearing on account of a reduction in the vegetative growth caused by a delay in sowing and this defect was partially counteracted by adoption of closer spacing than the normal spacing of three feet between rows and one and a half feet between plants. It was, therefore, necessary to determine how far the sowings of cotton in the different tracts in Sind could be delayed so as to minimise damage caused by 'bad opening' of bolls

and the red leaf blight without in any way reducing the yields by a decrease in bearing. The optimum sowing periods for cotton in the different tracts that would give maximum yields had to be determined by adopting the measure of closer spacing between rows and between plants.

The first reference to the optimum sowing period for cottons in Sind was found in the final report of the Sind Physiological Scheme financed jointly by the Sind Government and the Indian Central Cotton Committee from 1927 to 1937. The recommendations for cotton sowings were based on the sowing date experiments conducted in the Scheme. It is stated on page 59 of the report written by Sankaran (1938) : "If due weight is given to these results it would appear that April has been the optimum sowing period during all years and can therefore be recommended. It must, however, be remembered that the results are applicable to middle Sind (Nawabshah district in which Sakrand is situated). In South and East Sind (Hyderabad and Tharparkar distrricts) which are characterised by milder climate the sowings may have to be earlier."

The above recommendations have not been adopted as the Departmental recommendations as given in the Departmental Leaflet No. 48 (2nd Edition : 1943) were entirely different and were apparently based on the experiments conducted by the Departmental staff. The recommendations for sowing of cotton for these tracts were : (1) Jamrao Tract (East Sind) End of March to end of April (2) Hyderabad Tract (South Sind)—15th April to 15th May and (3) North and Middle Sind—15th May to 15th June.

In all previous experiments conducted in Sind spacing was not included as a separate factor for study in the sowing date trials. It is recommended to sow cotton at a distance of 3 feet between rows irrespective of sowing date in the sowing period. It would be shown below that May sowings in Hyderabad and June sowings in Middle Sind should be done closer than at 3 feet distance to give maximum yields. It was, therefore, necessary to include different spacings in the sowing date experiments that were primarily conducted to determine how far sowings of cotton could be delayed so as to minimise 'bad opening' of bolls and to give highest out-turn per acre.

Factorial experiments consisting of all combinations of two to four sowing dates and two to five varieties of Sind-American and Punjab-American cottons were conducted from 1943 to 1946 in East Sind, South Sind, Middle Sind and North Sind. The design and layout of these experiments were similar to those arranged in the Punjab and therefore they are not described in detail. In some of the experiments spacing was included as a separate factor to determine the best combinations of spacings with sowing dates as the sowing date advanced while in other experiments in view of the established relation between sowing date and spacing in the Punjab experiments, the spacing was reduced to 3 feet, 2½ feet, 2 feet and 1½ feet as the sowing date advanced by about a fortnight. The plant to plant distance was always kept equal to half the row to row distance at the time of final thinning.

The results of the sowing date experiments conducted in the four different tracts are given below which would indicate the optimum sowing period for each tract from the point of view of yields.

At Denisar in East Sind the optimum sowing period appeared to be between 6th April and the end of April (Table LXXII) but in other experiments (Table LXXIII-Expt. Nos. 3 to 6) the May sowing gave higher yield than the early April sowing. Similar remarks applied to Mirpurkhas. In other experiments conducted at Mirpurkhas or round about Mirpurkhas the June sowing gave very low yield (Table No. LXXIII-Expt. No. 14). The same remarks applied to the experiments conducted at Hyderabad and at Sakrand (Table LXXII).

TABLE LXXII.

Yield in maunds per acre under different sowing dates in different tracts.

Variety.	Experiment No. 12 Mirpurkhas (1943) (East Sind) Sowing date 9th April	30th April	20th May	10th June	Mean (+0.340)	Variety.	Experiment No. 5 Denisar Estate (1945) (East Sind) Sowing date 6th April	25th April	15th May	6th June	Mean (+0.40)
M4 ..	16.2	19.5	20.5	18.8	*18.7*	M4 ..	15.0	17.0	13.0	8.0	*13.3*
Sind Sudhar ..	10.3	12.9	18.4	13.6	*13.8*	L. S. S. ..	13.6	14.1	12.0	6.6	*11.6*
						289F/124 ..	13.7	14.6	10.8	4.6	*10.9*
Hybrids ..	5.0	7.7	13.7	8.8	*8.8*	289F/199 ..	11.2	15.2	12.3	7.0	*11.4*
						Cambodia ..	12.8	13.9	10.4	4.6	*10.4*
Mean(+ 0.575)	*10.5*	*13.4*	*17.5*	*13.8*		Mean (+0.93)	*13.3*	*15.0*	*11.7*	*6.2*	

Variety.	Experiment No. 20 Hyderabad (1945) (South Sind) Sowing date 30th April	21st May	11th June	Mean (+0.46)	Variety.	Experiment No. 24 Sakrand (1943) (Middle Sind) Sowing date 14th May	3rd June	24th June	17th July	Mean (+0.475)
M4	23.5	21.9	25.6	*23.6*	M4	12.6	12.2	13.2	12.9	*12.7*
Sind Sudhar ..	17.2	18.5	17.8	*17.8*	Sind Sudhar ..	10.7	10.1	11.2	12.1	*11.0*
L. S. S. ..	15.5	18.6	21.7	*18.6*	289F/K25 ..	11.3	11.0	13.3	12.3	*12.0*
289F/124 ..	20.3	19.3	17.0	*18.9*	289F/124 ..	11.1	11.1	13.1	12.3	*11.9*
289F/199 ..	16.7	17.5	18.4	*17.5*						
Mean (+1.09)	*18.6*	*19.2*	*20.1*		Mean (+0.99)	*11.4*	*11.1*	*12.7*	*12.4*	

The main difficulty in field experimentation that was encountered in Sind was the ununiform stand of the crop in the plots. It was difficult to get an uniform stand in all experimental plots. In some experiments half of the total experimental area was devoid of plants. The chief factors that produced gappiness were white ant, root rot and saline patches. It was also considered not very accurate to make suitable corrections for stand by adopting standard methods as the plants in and bordering the gaps produced very vigorous growth which they would not do if they were surrounded on all sides by other plants. As the gaps were too many, population showing such abnormal growth was great.

(*vii*) Results of all the sowing date experiments in Sind.

In all, 38 complex experiments were conducted in Sind in order to determine the optimum sowing period of commonly cultivated varieties of cotton by adopting the measure of closer spacing as the sowing date advanced. These experiments were laid out in 5 tracts: (1) South-East Tharparkar; (2) North-West Tharparkar; (3) Hyderabad; (4) Middle Sind and (5) North Sind to determine small differences in the optimum sowing periods even in the different parts of the same tract. Some of the experiments were conducted by the Departmental staff under the guidance of the author. Some of these experiments (marked with asterisks in Table No. LXXIII), were spoiled either on account of locusts, root rot, saline land, white ants or failure to keep spacing as required for the later sown crops. These defects in the experiments were kept in mind while arriving at final conclusions regarding the optimum sowing time for cotton in each tract.

The mean yield averaged for all treatments under each sowing date with appropriate standard error for each experiment is given in Table No. LXXIII. The year and the name of the place where the experiment was conducted are also given.

(*viii*) Optimum sowing periods for cotton in Sind.

In deciding upon the optimum sowing time for cotton from the results of the experiments conducted in Sind the differential effect of spacing and nitrogen on different sowing dates will have to be taken into account. In Table No. LXXIII only mean yields are given and the mean yields under later sowings are much lower than they are under close spacing alone. In experiment Nos. 4, 14, 15, 18, 23, 26 and 27, different spacings, wide, medium and close, were included as separate treatments and the mean yield under each sowing date was an average of the three spacing types. This mean yield under last sowing date was therefore lower than the mean yield obtained under close spacing alone as the depressing effects of wide and medium were included in the former. The same was not the case with the early sowings where closer spacing did not prove disadvantageous to them from the yield point of view.

Similarly early sowings gave much higher increases in yields by manuring than late sowings; hence in arriving at final conclusions the results of yield under different sowing dates in the absence of manuring will have to be considered.

There were also other environmental and local factors that must be taken into consideration in fixing the sowing periods and they are briefly mentioned below.

The climatic conditions in the Tharparkar and Hyderabad tracts (South and East Sind) at the fruiting stage were such that there was no possibility of an increase in the intensification and the spread of 'bad opening' of bolls and causing cotton failures as had been the case in the Punjab. In this major American cotton growing tract the 'bad opening' of bolls would be only confined to highly saline lands. It was not therefore necessary to delay the sowings too long in this tract as that would entail other disadvantages mentioned below.

TABLE LXXIII

Mean yields per acre under different sowing dates in Sind (1943-1946),

Expt. No.	Place	Year	Sowing dates				S. E.
	SOUTH-EAST THARPARKAR (Optimum sowing time=1st April to 15th May)						
1	Denisar Estate	1943	23rd March 14.9	6th April 16.3	20th April 15.6	4th May 13.9	±0.76
2	,, ...	1943	2nd April 18.86	23rd April 18.96	16th May 18.85	3rd June 16.51	±0.878
3	,, ...	1944	25th March 6.99	15th April 10.20	4th May 9.44	24th May 7.95	±0.406
4	,, ...	1944		22nd April 10.88		23rd May 9.58	±0.502
5	,, ...	1945	6th Apri 13.3	25th April 15.0	15th May 11.7	6th June 6.2	±0.93
6	,, ...	1946	1st April 12.1	15th April 11.6	30th April 12.8	15th May 13.5	±0.636
7	Kinjhejhi	1943	29th March 13.02	19th April 17.41	9th May 17.44	30th May 18.51	±0.927
8	,, ...	1944	8th April 18.13	26th April 18.21	15th May 19.86	3rd Jun 15.97	±0.84
9	*Jamesabad	1945	28th March 7.1	15th April 7.7	3rd May 6.3	21st May 4.3	±0.478
10	*Umarkot	1945	28th March 21.8	15th April 15.5	3rd May 12.8	21st May 10.0	±0.98
11	*Talhi	1945		20th April 12.3		18th May 8.3	±0.50
	NORTH-EAST THARPARKAR (Optimum sowing time=10th April to 25th May						
12	Mirpurkhas-Cotton Botanist's Farm .. .	1943	9th April 10.50	30th April 13.39	20th May 17.56	10th June 13.76	±0.525
13	Mirpurkhas-Etheldune Farm ..	1943	13th April 7.85	4th May 6.89	24th May 7.38		
14	Mirpurkhas Seed Farm ..	1945	2nd May 17.2	18th May 16.9	31st May 12.2	14th June 8.1	±1.18
15	,, ...	1946	8th April 13.9	23rd April 14.3	8th May 14.8	25th May 14.7	±0.88
16	*Tandoallahyar .. .	1945	15th April 22.0	3rd May 21.9	20th May 19.7	8th June 18.4	±1.20
17	Tando Jam	1946	22nd April 18.1	5th May 13.5	20th May 18.5	2nd June 12.4	±1.65
	HYDERABAD (Optimum sowing time=15th April to 30th May)						
18	Hyderabad .. .	944	22nd April 13.89		23rd May 15.93		±0.594
19	,, .. .	1944	17th April 21.51	5th May 17.07	3rd June 15.05	24th June 15.29	±1.15
20	,, ...	1945	30th April 18.6	21st May 19.2	11th June 20.1		±1.09
21	,, ...	1946	15th April 16.9	30th April 14.8	15th May 12.1	30th May 12.8	±1.18
22	Oderolal	1945	5th May 20.5	17th May 21.2	2nd June 18.4	16th June 17.5	±1.76

TABLE LXXIII—*contd.*

Expt. No.	Place	Year	Sowing dates				S. E.
			HYDERABAD—*contd.*				
23	Oderolal	1946	19th April 16.1	4th May 11.7	19th May 11.1	3rd June 14.1	±0.99
		MIDDLE SIND (Optimum sowing time=20th May to 30th June)					
24	Sakrand	1943	14th May 11.44	3rd June 11.10	24th June 12.72	17th July 12.42	±0.99
25	Sakrand, A. R. S.	1943	22nd May 15.77	10th June 15.99	3rd July 14.34	22nd July 17.07	
26	,, ...	1944	25th May 16.15		25th June 14.33		±0.587
27	,, ...	1944	25th May 14.43		25th June 10.56		±0.911
28	,, ...	1945	20th May 13.4	9th June 11.4	20th June 11.5		±0.99
29	,, ...	1946	18th May 9.9	3rd June 12.7	22nd June 11.5	8th July 9.3	±0.92
30	*Nawabshah	1944	1st June 15.18	20th June 16.14	7th July 12.22	27th July 3.06	
31	,, ...	1946	10th May 20.0	25th May 18.6	10th June 18.1	26th June 21.0	±1.08
32	*Pad Idan Farm	1945	21st May 24.0	8th June 16.0	26th June 18.8	14th July 17.2	±1.55
33	,, ...	1946	22nd May 10.3	7th June 11.2	22nd June 9.6	7th July 11.0	±0.50
34	*Tharushah	1945	21st May 14.3	8th June 11.6	26th June 14.8	14th July 11.5	±0.80
			NORTH SIND				
35	Dokri A. R. S.	1943	21st May 6.66	12th June 10.89	1st July 10.00	21st July 5.90	±1.246
36	,, ..	1943	6th June 7.43	27th June 9.72	10th July 8.80	28th July 5.66	±0.896
37	,, ...	1945	21st May 7.7	8th June 9.2	26th June 7.6	14th July 9.45	±0.940
38	*Dadu Farm	1945	6th June 6.0	24th June 4.0	10th July 4.0	22nd July 2.2	±0.659

There was also an earlier onset of reproductive phase in the month of June in this tract as compared with other tracts where the reproductive phase sets in in the month of July or August. It was, therefore, necessary to plant the crop sufficiently early to enable it to produce adequate vegetative structure before fruiting begins; otherwise there would be a great reduction in bearing points per acre which cannot be made up by even adopting closer spacing.

It was also not practical to delay sowings which would necessitate the adoption of close spacing than 2 feet between rows as the cultivators may not drill cotton seeds at a closer distance than 2 feet in order to keep adequate space between the rows for interculture. It may be stated here that the major part of the cotton crop in Sind was at present broadcast and not drilled and in order to give effect to these recommendations, cotton will have to be sown in lines.

The danger of damage caused by Jassids especially to late sown crop was always there as both the Sind-American varieties M4 and Sind Sudhar were susceptible to this insect pest.

It was also necessary to safeguard against delays in sowing caused by unforeseen factors such as canal closure, untimely showers of rain and this can be avoided by starting sowings earlier than the date arrived at from the results of the experiments.

The Department of Agriculture, Sind, has recommended, as stated before, a sowing period of 30 days for each tract. In view of what is stated above it was considered advisable to fix a 40 to 45 day sowing period so that sowings can be completed in time in spite of unforeseen difficulties. If, however, a cultivator can manage to sow all his cottons in a shorter period than the one recommended below he can start this sowings with advantage 10 to 15 days later than the dates indicated below.

It was found, by experience, advantageous to sow all unfertile or poor lands in the first half of the sowing period recommended as later sowings have been found greatly depressed in growth and very liable to Jassid damage on such lands.

As all the experiments arranged in North Sind (with the exception of Experiments Nos. 35 and 36 of 1943) were spoiled either on account of root rot, white ants or frost, no recommendations for the optimum sowing period for cotton in that tract could be made. It may be stated here that the acreage under Americans in North Sind was very small and negligible and the sowing period in North Sind was found more or less to correspond with the sowing time in Middle Sind.

The following Table LXXIV gives the recommended sowing periods for cotton in the different tracts after taking into consideration the results of all the experiments and the various points discussed above.

TABLE LXXIV.

Optimum sowing time for American cotton in different tracts of Sind.

Tract.	Sowing period.	Spacing in 1st fortnight of the sowing period.	Spacing in 2nd fortnight of the sowing period.	Spacing in 3rd fortnight of the sowing period.
South-East Tharparkar	1st April to 15th May	$3' \times 1\frac{1}{2}'$	$2\frac{1}{2}' \times 1'$	$2' \times 1'$
North-East Tharparkar	10th April to 25th May	,,	,,	,,
Hyderabad Tract ..	15th April to 30th May	,,	,,	,,
Middle Sind	20th May to 30th June	,,	,,	,,

The spacing was kept as a separate factor for study in several experiements (Experiment Nos. 4, 12, 14, 15, 18, 23, 27, 32, 33 and 37 in Table LXXIII) and the necessity of adopting closer spacing than 3 feet between rows for the late sown crops

was completely borne out by the results of these experiments with some exceptions. In some experiments closer spacing than 3 feet between the rows even proved beneficial for the early sown crop while in other experiments there was no benefit derived by closer spacing than 3 feet between the rows. In majority of experiments late sown crops when spaced at 3 feet distance gave very low yields as compared with the yields obtained with closer spacings. The spacings recommended above (Table LXXIV) for each fortnight of the sowing period for each tract have been partly based on the results of the experiments and partly on observations made on the crops sown at different dates with different spacings. It was determined under which combination of spacing and sowing date the crop had covered the ground by the meeting of the adjoining rows of cotton plants. If the sowings are required to be done after the last dates given above, the crops should be sown at a distance of 1½ feet between rows and thinned to 9 inch distance within the row.

Table LXXV.

Yield in maunds per acre under different combinations of sowing dates and spacing.

Spacing between rows	Experiment No. 12 Mirpurkhas (1943) (South Sind) Sowing dates					Spacing	Experiment No. 22 Oderolal (1945) (Hyderabad Dist.) Sowing dates				
	9th April	30th April	28th May	10th June	Mean ($\pm$0.855)		5th May	17th May	2nd June	16th June	Mean ($\pm$ 0.60)
1½ ft. ..	9.9	12.7	17.6	16.90	14.3	Close ..	21.0	23.7	19.1	19.3	
2 ft. ..	11.1	13.8	16.7	13.10	13.7	Medium .	21.6	21.0	17 4	17.0	
2½ ft. ..	11.2	13.8	19.2	14 0	14.5	Wide . ..	18.8	18.8	18.6	16.2	
3 ft. ..	9.8	13.0	16.8	10.8	12.7						
Mean ($\pm$0.525)	*10.5*	*13.4*	*17.6*	*13.3*		Mean ($\pm$1.76)	*20.5*	*21.2*	*18.4*	*17.5*	

As the number of cotton rows will increase as the spacing between the rows is reduced from 3 feet to 2 feet, it would be necessary to increase proportionately the seed rate per acre in order to get the required stand. The standard seed rate recommended by the Department of Agriculture for cottons sown at 3 feet distance was 24 lbs. per acre. So the seed rate will have to be increased to 28 lbs. and 32 lbs. per acre for the cotton sowings in the second and the third fortnight of each sowing period. In the experiments conducted in Sind slightly higher seed rates than those given above were used to ensure the spacings required to be kept.

The Sind-American strain M4 gave higher yields per acre varying from 1½ maunds to 5 maunds (Table LXXII) than the other strain Sind Sudhar in 27 experiments out of a total of 37 experiments in which two varieties were included. In the remaining experiments the yields of the two varieties were nearly equal. This difference in the yielding capacities of the two varieties was greater in the South and East Sind than in the Middle Sind where Sind Sudhar gave as high yields as M4. This may have some relation to the places where these strains were evolved. M4 was evolved in South Sind while Sind Sudhar was evolved in Middle Sind.

Another noticeable feature of M4 was its greater suitability for late sowing than Sind Sudhar. The sowings of M4 could therefore be delayed, without reducing the yields, for a longer period than the other variety.

CHAPTER XIII.

THE RED LEAF DISEASE IN SIND-AMERICAN COTTONS.

(i) General.

The reddening of leaves in American cottons was not an uncommon phenomenon. It has been reported to occur in many parts of India where American cottons are grown. Burt and Haider (1919) reported this phenomenon in Cawnpore-American cottons in the United Provinces, and later the same 'disease' was reported by Kottur (1920) from Dharwar and by Prayag (1927-28) from Khandesh. The reddening of leaves was also found to occur in the Punjab during the years when cotton crop failed in that Province (Milne, 1921 and 1922). It was found to be present by Sawhney (1932) in Hyderabad (Deccan). The read leaf 'disease' was also of common occurrence in Sind (Dabral, 1938). It was also found to occur in the American Upland cottons grown in Central India (Rao and Wad, 1936). Thus it was a 'disease' appearing in all parts of India where American cottons were grown.

As the red leaf in *hirsutum* cottons has been reported to occur under different conditions of soil and climate, it is possible that the causes that give rise to this common symptom in the leaves may be different. It appears the leaves of *hirsutum* cottons have a tendency to redden whenever they become senescent either prematurely or at the end of the life cycle.

The red pigment in the leaves of *hirsutum* cottons is also found to develop as a result of injury caused by Jassids (Sawhney, 1932). The injury causes the death of leaf tissues and the red pigment subsequently develops. This investigation deals with the red leaf that occurs in Sind in the absence of Jassid injury.

Dabral (1938) had differentiated the red leaf 'disease' that occurred in Sind-American cottons into different types of which one was caused by a deficiency of nitrogen and this was cured by the application of various fertilisers containing nitrogen. It will be shown below that yellowing and not reddening was a symptom of nitrogen deficiency while reddening was an after-effect that followed yellowing. In many cases reddening after yellowing did not occur. It has already been shown (Chapter III) that yellowing of leaves that occurred in the Punjab-American cottons in the Punjab was caused by a deficiency of nitrogen in light sandy soils but where the development of the red pigment was not found to be of general occurrence.

The yellow-red leaf disease in Sind American cottons has been found to occur mainly in the South and East Sind which was the most important American cotton tract in Sind. This trouble appeared to be more frequent and widespread in this tract than in any other tract. In fact it has been found to be present every season.

The previous findings of Dabral (1938) were based on the work done at Sakrand which was situated in Nawabshah district in Middle Sind where the red leaf was neither acute nor so widespread. It was, therefore, considered necessary to conduct the investigations in the Tharparkar and Hyderabad districts where this disease was found to be of common occurrence. The climatic conditions in South Sind as already stated were different from the climatic conditions prevailing in Middle Sind and it therefore appeared likely that this difference in the climatic conditions may be causing greater and more frequent incidence of the disease in the former tract.

(ii) Two types of leaf reddening.

Observations made on the cotton crop in Sind during the cotton season of 1942-43 showed that the reddening occurred in two ways and this difference has been, on further investigation, found to be of such great importance that the red leaf can be classified into two main types. In one type the change in colour of the leaf from green to red took place through the intervening stage of yellowing. The leaves first turned pale and yellow before the red pigment developed. In this type of reddening, the leaves sometimes turned deep red or scarlet in colour. In the second type the change in colour from green to red occurred without the intervening stage of yellowing. The leaves in such cases turned bronze or copper coloured. The two types can be distinguished from a distance. Both the types were found to occur in the different parts of the same block of land in Sind.

The analysis of the soil samples taken from the spots where these two types of red leaf occurred revealed important differences in their physical properties (Table LXXVI).

Table LXXVI.

Mechanical analysis of the soil under yellow-red and green-red Sind-American cottons.

Depth in feet.	Yellow-red.			Depth in feet.	Green-red.		
	Clay per cent.	Silt per cent.	Sand per cent.		Clay per cent.	Silt per cent.	Sand per cent.
1st ft.	7	14	76	1st ft.	24	30	46
2nd „	11	17	72	2nd „	37	32	31
3rd „	9	26	64	3rd „	43	40	17
4th „	9	34	56	4th „	45	45	10
5th „	15	39	45	5th „	48	46	6
6th „	23	54	42	6th „	48	44	8

The soil under yellow-red type was light sandy containing a very high percentage of sand and low percentage of clay while the soil under green-red type was heavy containing low percentage of sand and high percentage of clay.

The physical texture of Sind soils varies in between the two limits given above and it would be difficult to distinguish the yellow-red from the green-red when the proportions of sand and clay fractions are in between these two extremes. It was, however, noted that the yellow-red type was distinguishable when the soil was composed of about 60 per cent or more of sand and 8 to 12 per cent of clay. Under lesser proportion of sand fraction yellowing prior to reddening could not be properly distinguished.

(*iii*) Causes for the yellow-red leaf.

It was experimentally proved in the cotton season of 1943-44 that the yellow-red leaf occurred on account of a deficiency of nitrogen in such light sandy lands. A light sandy field where the red leaf was reported to occur in previous seasons was selected at Denisar Estate, Nabisar Road, Sind. A sowing date-cum-manurial experiment consisting of 8 randomised blocks of 4 main plots each for 4 different sowing dates was laid out. Each main plot was split into two sub-plots for control and 33 lb. N per acre treatments. Nitrogen was applied in the form of sulphate of ammonia on 5th June. The variety was L.S.S., a Punjab-American variety grown on this estate.

Observations on the crop showed that the leaves turned first pale and later red during the fruiting period in the months of August-September in the unmanured plots of the first two sowings while it was green in all the manured plots. The yellow-red leaf generally occurred at a much later date in the 3rd and the 4th sowings of the unmanured plots. Manuring was also found to have a beneficial effect on yields but the increase in yield produced by manuring declined in magnitude as the sowing date advanced (Table LXXVII).

Table LXXVII.

Yield in maunds per acre.

Sowing date.	23rd March.	6th April.	20th April.	4th May.	Mean.	S.E.
Manured	18.1	19.1	17.0	14.5	17.2	± 0.50
Unmanured	11.7	13.5	14.1	13.2	13.1	

Another similar experiment to study the effect of the application of sulphate of ammonia on the yellow-red leaf in Sind-American cottons in light sandy land in the Middle Sind was laid out in the same season at the Agricultural Research Station, Sakrand. Though the fields selected were light sandy there were saline patches scattered irregularly all over the area. The experiment consisted of 3 randomised blocks of 12 main plots each in which all combinations of 4 sowing dates (14th May, 3rd June, 24th June and 17th July) and 3 nitrogen treatments (control, 40 lb. N per acre in the form of sulphate of ammonia at sowing and 40 lb. N per acre in the form of sulphate of ammonia at flowering) were randomised. Each main plot was split for four varieties (M4, Sind Sudhar, 289F/K25 and 289F/124). Thus it was intended to study the effect of the early and late application of the manure on the development of the red leaf in the case of two Sind-American (M4 and Sind Sudhar) and two Punjab-American (289F/K25 and 289F/124) varieties. (Experiment No. 24 in Table LXXIII).

The yellowing of the crop was first noticed in the month of September in the 1st sowing while it did not appear in the 4th sowing in the unmanured plots. The manured plots showed no yellowing except in the case of the first sowing where yellowing developed in the October indicating that the dose of nitrogen applied did not prove adequate to prevent yellowing in the early sown crop. It was also noticed

that though there was yellowing of the leaves there was very little leaf reddening in this experiment. The crop was, however, very patchy in most of the plots on account of the presence of alkali or saline patches. In such patches the crop did not show yellowing.

TABLE LXXVIII.

	A Yield in maunds per acre					B Weight of seed cotton per boll in gm.			
	Control	Sulphate of ammonia before sowing (40 lb. N per acre)	Sulphate of ammonia at flowering (40 lb. N per acre)	Mean ($\pm$0.51)		Control	Sulphate of ammonia before sowing (40 lb. N per acre)	Sulphate of ammonia at flowering (40 lb. N per acre)	Mean ($\pm$0.092)
M4 ..	11.0	13.7	13.5	12 8	M4 .	2 65	2 93	2.93	2.84
Sind Sudhar	9.8	10.4	13 1	11 1	Sind Sudhar	2.22	2 36	2 49	2.35
289F/K25 ..	9.8	11.7	14.3	11.9	289F/K25	2.54	2 58	3.05	2.72
289F/124	9.7	12 7	13.2	11.9	289F/124	2.71	2.78	2 83	2.77
Mean .. ($\pm$0.85)	10 1	12 2	13.5		Mean ($\pm$0.102)	2.53	2 66	2.82	

There was a significant increase in the mean yield of all varieties as a result of late application of sulphate of ammonia (Table LXXVIII-A). The early (at sowing) or the late (at flowering) application of the fertiliser proved equally effective in increasing the yield of two early maturing varieties M4 and 289F/124 while the late application of sulphate of ammonia proved more efficacious than the early application in the case of two late maturing varieties; Sind Sudhar and 289F/K25. Thus application of sulphate of ammonia lessened the yellowing of leaves and increased the yields. It also increased the seed maturity as the boll weight determinations showed (Table LXXVIII-B). There was significant increase in boll weight (*i.e.* seed cotton per boll in gm.) in manured plots and late application was found to give the maximum increase in boll weight.

(*vi*) RELATION BETWEEN THE YELLOW-RED LEAF AND NITROGEN CONTENT OF THE LEAVES.

Further experimental evidence to show that a low nitrogen content of the leaves was associated with yellow-red leaf was obtained in the cotton season of 1944-45. A common experiment on sandy fields at three places *viz.* Nabisar Road, Hyderabad and Sakrand was laid out. It consisted of all combinations of two sowing dates, two levels of nitrogen (O, 50 lb. N at flowering) and two spacings (s1=2 ft. and s2=2½ ft. between rows). Each plot was split to accommodate three varieties M4, Sind Sudhar and L.S.S.. In order to correlate the yellow-red leaf with nitrogen content, fortnightly leaf samples from two replications of all the 24 combinations in the experiment at two centres *viz.*, Nabisar Road and Hyderabad were taken. 4-plant sample under wide spacing and 8-plant sample under close spacing were taken at random in duplicate. The leaves were analysed for nitrogen. Regular observations were recorded on the appearance of the red-leaf under each treatment at the time of sampling. The results of nitrogen contents of the leaves are given in Table LXXIX below.

TABLE LXXIX.

Mean percentage nitrogen in leaves on different dates at two centres.

VARIETIES

Denisar.					*Hyderabad.*				
Date of Sampling.	M4.	Sind Sudhar.	L.S.S.	S.E.	Date of Sampling.	M4.	Sind Sudhar.	L.S.S.	S.E.
28th July ..	3.22	2.96	2.83	0.041	23rd July ..	3.47	3.19	2.96	0.028
13th August ..	3.08	2.87	2.75	0.047	7th August ..	3.14	2.91	2.70	0.020
29th August ..	2.51	2.30	2.21	0.035	23rd August ..	2.66	2.46	2.50	0.022
14th Sept. ..	2.21	1.88	1.74	0.058	7th Sept. ..	2.31	2.07	1.87	0.022
					23rd Sept. ..	1.79	1.64	1.47	0.031

NITROGEN

Denisar.				*Hyderabad.*			
Date of Sampling.	Manu-red.	Control.	S.E.	Date of Sampling.	Manu-red.	Control.	S.E.
28th July ..	3.32	2.68	0.052	23rd July ..	3.39	3.02	0.035
13th August ..	3.31	2.49	0.055	7th August ..	3.03	2.80	0.034
29th August ..	2.66	2.03	0.062	23rd August ..	2.78	2.29	0.043
14th Sept. ..	2.14	1.75	0.058	7th Sept. ..	2.28	1.88	0.029
				23rd Sept.	1.70	1.56	0.034

SOWING DATE

Denisar.				*Hyderabad.*			
Date of Sampling.	Late sowing.	Early Sowing.	S.E.	Date of Sampling.	Late sowing.	Early sowing.	S.E.
28th July ..	3.11	2.89	0.052	23rd July ..	3.49	2.92	0.035
13th August ..	3.22	2.58	0.055	7th August ..	3.18	2.65	0.034
29th August ..	2.50	2.19	0.062	23rd August ..	2.85	2.22	0.043
14th Sept.	2.12	1.78	0.058	7th Sept ..	2.38	1.78	0.029
				23rd Sept. ..	1.79	1.47	0.034

The study of the results of the nitrogen contents of the leaves in relation to the time of appearance and the spread of the yellow-red leaf at the two centres disclosed in general terms the following relationships between the yellow-red leaf and the nitrogen contents of the leaves under different treatments.

M4 on the whole showed the least yellowing and reddening of the leaves while L.S.S. showed the symptoms at a very early stage and in a very intense form. The concentration of nitrogen in the leaves of M4 remained significantly higher at each stage of growth than the concentration of nitrogen in the leaves of the other two varieties. The leaves of L.S.S. showed the least concentration of nitrogen (Table LXXIX). Thus yellow-red leaf appeared to be definitely related to the nitrogen concentration in the leaves.

The manured plots of all the varieties showed much less yellowing and reddening than the corresponding unmanured plots during the fruiting period. These symptoms appeared only in the leaves in some of the manured plots of the first sowings of L.S.S. or Sind Sudhar. The concentration of nitrogen in the leaves of the manured plots was also found to be significantly higher at each stage of growth than the concentration of nitrogen in the leaves of the control plots (Table LXXIX).

The late-sown crop generally showed less yellowing and reddening than the crop sown early. The concentration of nitrogen in the leaves of the late sown crop was found to be significantly higher at each stage of growth than the concentration of nitrogen in the leaves of early sown crop.

It was clear that yellowing and reddening of the leaves in American cottons in Sind was associated with a low concentration of nitrogen and was a symptom of nitrogen deficiency. It may be stated here that the selection of plants for analysis of the leaves was at random. The plants were first randomised and then taken for analysis at each date. The term yellowing-reddening used above does not necessarily mean that each and every plant in a plot or all the leaves of a plant had turned yellow-red. Though the general appearance of the crop in a plot indicated yellowing some leaves of some of the plants may be green or pale green.

The abovementioned conclusions regarding the relation between nitrogen content and the yellow-red leaf were further supported by the yield data obtained in the common experiment. (Table LXXX).

Table LXXX.

Yield in maunds per acre.

	Denisar		Hyderabad		Sakrand		Mean		Increase due to manuring.
	Control	Manured	Control	Manured	Control	Manured	Control	Manured	
M4	10.36	14.17	14.67	18.84	11.55	15.66	12.19	16.23	+4.04
Sind Sudhar	7.56	8.94	11.06	14.61	9.89	15. 20	9.50	12.92	+3.42
L. S. S.	8.86	11.50	12.38	17.91	7.98	14.75	9.74	14.72	+4.98
Mean	8.92	11.54	12.70	17.12	9.80	15.20	10.48	14.62	+4.14
Increase due to Manuring	+2.	62	+4.	42	+5.	40	+4.	14	
S. E. (Var.)	0.251 =	2.45%	0.326 =	2.19%	0.695—	5.58%	of the me	an	
S. E (Nitr.)	0.502 =	4.91%	0.549 =	3.68%	0.587—	4.71%	of the me	an	

M4 gave the highest yield both under manured and unmanured conditions at all the three centres. It had the highest nitrogen content and was found resistent to yellow-red leaf. Manuring gave substantial increases in yields varying from 2.62 to 5.40 maunds per acre. It has already been shown above that manuring had increased the nitrogen content and had at the same time decreased the red leaf.

(v) The relation of weather factors with the incidence of yellow-red leaf.

The complaints of red-leaf were generally received more frequently from Southern parts of Sind than from Middle Sind. The yellow-red leaf was found to be generally present in many fields in the former tract. How can the greater prevalence of this trouble in the southern parts of Sind be explained if nitrogen deficiency in light sandy soil was the root cause of this trouble as light sandy lands were as widely distributed in Middle Sind as in South Sind ? The red leaf trouble was found to be even of less frequent occurrence in the Punjab than in Middle Sind even though there are vast areas in the Punjab which are light sandy.

Further investigations conducted on this problem have revealed that the wide spread occurrence of yellow-red leaf in southern parts of Sind was a result of the interaction of soil factor with the climatic factors prevailing in that tract.

Two Sind-American varieties, M4 and Sind Sudhar, and one Punjab-American variety, L.S.S., were grown at three centres in South Sind (Denisar Estate, Nabisar Road), in Middle Sind (Sakrand) and in the Punjab (Iqbalnagar). A common sowing date-cum-varietal experiment was laid out at the three centres. Though the object of the experiment was to study the growth of these three varieties under different sowing dates and under the climatic conditions prevailing in the three tracts, the observations made on the onset and the completion of the reproductive phase provided a clue for the cause of such frequent and widespread occurrence of the yellow-red leaf disease in South Sind. During the abovementioned study regular observations on the initiation and the completion of the reproductive phase of each of the three varieties at the three centres were recorded with a view to determine the main flowering period and the harvesting period. It was expected to provide information regarding the relation of climatic factors with the initiation and the completion of the reproductive phase of a variety. The main flowering and harvesting periods at the three centres for each variety are given below.

Table LXXXI.

(a) *Main flowering periods for the three varieties at the three centres.*

	South Sind (*Denisar Estate*).	Middle Sind (*Sakrand*).	Punjab (*Iqbalnagar*).
M4	17th July to 17th August	10th August to 10th September	16th August to 13th September
Sind Sudhar	5th August to 15th September	20th September to 20th October	23rd September to 19th October
L.S.S.	30th July to 30th August	25th August to 20th September	15th September to 15th October

(*b*) *Harvesting periods for the three varieties at the three centres.*

M4	September to October	October to December	October to December
Sind Sudhar	Mid-September to early November	November to January	November to January
L.S.S.	Do.	Do.	Do.

In South Sind there was an early initiation of flowering and setting and early completion of the fruiting phase and consequently early finishing of the crop. The general pickings in this tract started by the 1st or the 2nd week of September and were almost completed by the end of October or beginning of November at the latest while in the Middle Sind and the Punjab the pickings began by the second or the third week of October and were completed by the beginning of January. The crop finished off more quickly *i.e.* in less than two months in South and and East Sind than in Middle Sind and in the Punjab. This difference in the setting and maturation of the crop could be explained by the differences in the climatic conditions prevailing in these tracts as pointed out below.

Earliness or lateness of a variety was its inherent character but it can be modified by the climatic factors, as it was clearly brought out by this investigation. And early maturing variety may become late in a different environment and *vice versa*. L.S.S. which was a late maturing variety in its natural environment in the Punjab became early when grown in South Sind. It flowered, fruited and finished off earlier in the latter tract than in the former tract and in Middle Sind (Table LXXXI). Similarly M4 which was an early Sind variety became comparatively late under the Punjab and Middle Sind conditions. Thus the inherent character of earliness or lateness could be shifted forward or backward by climatic conditions even though the relative differences between an early and late variety would still persist in a given environment (Table LXXXI). M4 always matured earlier than L.S.S. in South Sind or in the Punjab while L.S.S. always matured later than M4 in the same two tracts.

The differences between the flowering and the harvesting periods in South Sind on one hand and Middle Sind and the Punjab on the other hand could be explained on the basis of the differences in the maximum and minimum temperatures and humidity prevailing in these tracts (Table LXXXII.)

TABLE LXXXII.

Monthly means of maximum and minimum temperatures and humidity.

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.
				South Sind (Hyderabad)						
Maximum	102.0	107.2	104.2	99.2	95.9	97.4	97.9	89.1	79.0	76.2
Minimum ..	72.1	78.2	81.7	80.9	79.0	76.2	70.1	58.9	52.3	50.6
Humidity at 8 A.M ..	47	54	62	68	70	68	56	52	55	57
				Reproductive phase						

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.
			Middle Sind (Sakrand)							
Maximum ..	102.0	111.0	110.0	104.0	102.0	102.0	101.0	89.0	78.0	74.0
Minimum ..	67.0	77.0	83.0	83.0	80.0	75.0	65.0	54.0	46.0	43.0
Humidity at 8 A.M. ..	53	53	63	71	73	74	68	69	76	73
						Reproductive phase				
				Punjab (Multan)						
Maximum ..	97.9	106.9	108.3	104.3	101.2	100.5	95.9	84.8	73.5	69.7
Minimum ..	68.4	78.1	84.2	84.3	82.6	77.5	65.1	53.5	45.0	43.3
Humidity at 8 A.M. ..	47	42	50	63	68	65	56	60	69	71
						Reproductive phase				

There was an early fall in the maximum temperature from the month of July in South Sind and it remained lower throughout the remaining part of the season. The minimum temperatures were throughout high during the fruiting and maturation period (August-October) in South Sind while in Middle Sind and the Punjab the later part (October-December) of the fruiting and maturation period was characterised by a rapid fall in the night temperatures. The differences between maximum and minimum temperatures were also of a lower magnitude in South Sind. These differences in temperatures between South Sind on one hand and Middle Sind and the Punjab on the other may be responsible for the early initiation, setting and maturation of the crop in the former tract as explained below.

The fall in the maximum temperatures in July in South Sind gave rise to an early initiation of fruiting branches. High temperatures as shown by Balls (1919) retarded the stem growth as well as the formation of flowering branches. The fruiting branches were not generally formed as soon as the temperatures dropped but its effect became visible after a lapse of certain period from the day the temperature began to fall. The lower temperatures in August in South Sind also helped in the setting of bolls. As there was no great fall in the night temperature which remained well above 70° F. during the bolling and maturation period, the bolls matured very rapidly. As a result of numerous determinations it was found that the maturation period of bolls for all the the three varieties generally varied from 32 to 39 days. The crop therefore became early and finished off early, before the night temperatures fell below 70° F.

In the Punjab the temperatures began to fall in August and the initiation and the setting of the crop began to occur from the middle of August or the beginning of September according to early or late habit of a variety. The maturation period of bolls coincided with falling night temperatures. The night temperatures in October fell below 70° F. and they were still lower in the months of November and December (Table LXXXII). Consequently muturation occurred at a slower rate so much so that the maturation period of bolls increased from 45 days to 70 days. The maturation period of bolls of all varieties was found to increase from 45 days in the bolls set in August to 70 days for bolls set in October. The late set bolls continued to open up till the end of December or beginning of January in the late maturing varieties.

Though no differences in humidity recorded at 8 A.M. were found to exist in the three tracts during the reproductive phase the humidity during the day was known to be highet in South Sind than either in Middle Sind or the Punjab. It was also likely that higher humidity during the day minimised abscission and caused an early setting of bolls. Thus higher humidity may also contribute to an early setting and thus indirectly to an early maturation of the crop.

It has already been shown by the author in Chapter III (Dastur and Ahad 1941 and Dastur, 1941) that the nitrogen content of the leaves began to decline when the reproductive phase set in and the leaves began to turn pale and yellow when their nitrogen content fell to 1.5% of the dry matter of the leaves. The rapid maturation of the crop in South Sind brought about a quick depletion of nitrogen in the leaves and the nitrogen content of leaves, therefore, fell much below that level when yellowing started. The nitrogen contents of Sind Sudhar and L.S.S. under unmanured condition had fallen to 1.5% as early as the 1st week of September (Table LXXXIII) in the April-sown crop. The drain of nitrogen in the leaves was so great that young and mature leaves along with old leaves were found to turn pale and yellow. The nitrogen content of the leaves on manured land remained much above 1.5% during the maturation period and consequently yellowing did not occur even though the crop matured equally rapidly.

The cotton crop under Middle Sind and the Punjab conditions matured slowly on account of a fall in temperature in October and there was, therefore, no such rapid depletion of nitrogen from the leaves. The nitrogen content of the leaves of 4F remained above 1.5% upto the end of November. It was higher even in the month of November in the Punjab than in the month of September in South Sind in the may-sown crop (Table LXXXIII).

TABLE LXXXIII.

Percentage of nitrogen in leaves in South Sind and the Punjab.

Date	Hyderabad (South Sind) Sown on 15th April			Hyderabad (South Sind) Sown on 22nd May			Date	Lyallpur (Punjab) Sown on 14th May	Lyallpur (Punjab) Sown on 21st June
	M4	S. S.	L. S. S.	M4	S. S.	L. S. S.		4F	4F
23rd July ..	2.65	2.32	2.29	3.76	3.29	3.07	24th July ..	3.78	4.42
7th August ..	2.56	2.07	2.00	3.33	3.22	2.89	8th August ..	3.16	3.40
23rd August ..	2.32	1.83	1.89	2.14	2.08	2.09	22nd August ..	2.78	3.37
7th September ..	1.95	1.55	1.49	2.14	1.87	1.77	5th September	2.39	3.25
23rd September	1.65	1.30	1.15	1.88	1.46	1.46	19th September	2.33	2.69
							3rd October ..	2.46	2.72
							18th October ..	2.24	2.37
							1st November ..	1.73	2.35
							15th November ..	1.88	2.13

The yellowing, therefore, occurred in the Punjab towards the end of the maturation period except on light sandy lands. On the latter type of land yellowing occurred towards the end of September and it was found to be accompanied with a low nitrogen content in the leaves.

The yellowing and the subsequent reddening in *hirsutum* cottons in Sind, therefore, occurred on account of the operation of two factors : (1) light sandy lands deficient in nitrogen and (2) higher night temperatures during the fruiting period causing a rapid maturation of the crop. In the Punjab and Middle Sind yellowing occurred on account of the operation of the soil factor alone. Light sandy soils were widely distributed in all the three tracts but quick maturation of the crop in South and East Sind on account of the prevailing higher night temperatures at that time caused the trouble to spread on lands which were not very deficient in nitrogen, *i.e.* it spread to lands where normally the premature yellowing did not occur under Punjab conditions. The red leaf trouble was, therefore, more widespread in lower Sind than in the other two tracts. The variations in the nitrogen status of the soil from field to field caused variations in the intensity and the time of its appearance. The intensity and the spread of the red leaf trouble can also increase in South Sind if the month of September was characterised by spell of higher temperatures than normal as they would further hasten the maturation process and quicken the depletion of nitrogen from the leaves. Wherever there was quick depletion of nitrogen, the entire plant turned yellow-red while wherever the depletion was not so quick, some leaves turned yellow and some remained normal. The time of appearance and the intensity of the yellow-red leaf trouble would also be influenced by the previous crop, by manuring, by fallowing and by the sowing time of the crop. Once the leaves became depleted of nitrogen and became senescent organic acids accumulated and the anthocyanin pigments developed which turned red in the acid cell sap. The formation of red pigment was confined to epidermal cells only. It was observed that the formation of red pigment did not occur in the mesophyll cells of the leaves. Thus reddening of leaves was an after-effect of yellowing caused by a deficiency of nitrogen.

CHAPTER XIV.

CONCLUSIONS.

The Punjab-American cottons (G. *hirsutum*) when sown early in May make vigorous growth which is promoted by three factors, (1) sandy loam nature of the soil, (2) long summer days, and (3) regular irrigation water supply. The sandy nature of the soil is favourable for rapid growth of roots and consequently of shoots. The long summer days promote high photosynthetic activity and the regular water supply prevents the development of any disturbance in the normal functional activities of the plant. The plant is, therefore, able to produce an unusually large scaffolding with numerous branches and profuse foliage. The flowering begins from the 4th week of August. Any change in the sowing date is not accompanied by a similar shift in the setting in of the flowering phase. All plants tend to come into bearing within a narrow period irrespective of the time when the crop is sown. A delay of 20 days in sowing shifts forth flowering for not more than five to six days. The main flowering period lies in the month of September and ends by the middle of October. The early flowers produced in the end of August are mostly shed, while the bolls that set late in October crack prematurely on account of severe winter. The early sown crop could only be at an advantage, if the flowering period were also comparatively prolonged. As it is, the flowering occurs in a flush and 70% of these flowers are shed. The demand for nitrogen and other minerals is great and intense during reproduction but is inadequately met to ensure a sufficiently large fraction of flowers produced to reach full maturity. The plant consequently produces much less seed cotton in proportion to its size or dry weight. On the best of fields the seed cotton produced by a plant is nearly 20% of its total dry weight. The maximum dry matter is found in the stem of cotton when it is sown in May on sandy loam soils. The efficiency of the plant for fruit production is thus low. The cotton crop is, therefore, characterised by a high vegetative but a low reproductive growth.

The efficiency of the plant for boll production is further lowered on soils which are deficient in nitrogen. There is at first a vigorous vegetative growth but the symptoms of nitrogen starvation appear in the leaves when the plant is in the reproductive phase. The nitrogen content of the leaves falls to 1.5% as compared with 2.5% in the leaves of plants on normal soils. A yellowish chlorosis of leaves occurs, which is followed by early senescence. Flower and boll production are proportionately reduced, there being no difference in the percentage success of flowers into bolls. In addition, the maturity of seeds is low, each boll containing about 35% immature and a similar quantity of partially immature seeds. The number of seeds per boll is also reduced. It is not an uncommon sight to behold big sized plants with most of their leaves shed and bearing small bolls at the extremities of their branches. The efficiency of the crop for seed cotton production is further lowered to 10-12% on such soils.

The Punjab soils are chequered in nature. The normal soils are mixed with saline soils. The soluble sodium salts may be present in varying proportions in both the surface and the subsoil layers or they may be confined to the lower layers only. As the non-saline patches are intermixed with the saline, the cotton plant shows differential growth within a field. The plants do not either grow at all or make stunted growth when salinity is present on the surface. The stand of cotton thus becomes patchy. When the free sodium salts are present in the subsoil, the cotton plants, after making normal growth for some time, begin to suffer from a condition of physiological drought. This causes drooping of leaves and their premature shedding.

These symptoms may either appear in September or in October according to the degree of salinity and the - seasonal conditions. The bearing is reduced and the growth of developing bolls is arrested. The nature of disturbance that occurs in the boll metabolism and gives rise to seed immaturity has already been explained in Chapter VII. The efficiency of the crop for seed cotton production is also lowered on such soils.

The condition of physiological drought becomes further pronounced when the fruiting season in a certain year is marked by long spells of unusually warm and dry days. The water balance of the crop with the soil is further upset and the drooping, defoliation and premature boll opening are all intensified. These sumptoms make their appearance even on areas with low salinity in the subsoil. *Tirak* spreads to regions where it does not occur normally and thus attains a serious form in years of general failures.

The May-sown crop is, therefore, not in equilibrium with its edaphic and climatic environment on such saline soils. In years favourable for the growth of the crop these symptoms develop on small areas where salinity is very high in the subsoil but any weather factor that increases the water loss from the crop may lead to the intensification and spread of this trouble on extensive areas resulting in great losses in yield. Thus *tirak* is a case of physiological maladjustment at the fruiting stage.

The chief difficulty in understanding the causes of *tirak* and its widespread occurrence in certain years lay in the extreme heterogeneity of the Punjab soils. The premature defoliation of the crop and the immaturity of seeds were caused under two different soil conditions which are usually found intermingled. The soil heterogeneity thus rendered both observation and experiment difficult. A field produced *tirak* crop in one season but it bore normal crop in the other. Pure soil studies, even if they were attempted, would have yielded no information unless they were accompanied by a study of the crop in its physiological and chemical aspects.

The yellowing of leaves in one case and the drooping of leaves in the other paved the way for differentiating the two soil conditions on which *tirak* developed. The effects of the application of nitrogen and of extra water on the growth of the plant on the two soil types and the investigation of the chemical composition of the plant coupled with the soil analysis indicated the nature of the distrubances occurring within the plant.

Once the nature of the physiological disorder setting in the plant on the two soil types was discovered, the task of remedying this disorder became less difficult. The application of nitrogen to light sandy soils prevented the development of *tirak* symptoms caused by nitrogen starvation and the application of extra water at the fruiting stage prevented the development of physiological drought on soils with saline subsoils. Both these remedies proved specific for the two soil types and naturally they must be applied at the right place. The remedy for one soil type did not generally produce any effect when applied on the second type.

The importance of the June-sowings as a preventive measure against *tirak* was in its general applicability. It was found efficacious on all soil types as it put the crop in equilibrium with its surroundings. The June-sowings were found to be better adapted to its environment than the May-sowings. This was true of even normal soil where *tirak*-promoting conditions did not exist. The plants were able to carry on their normal functions with less nitrogen and less water and the deficiency

of these substances did not develop. The plants were also better able to stand the adverse weather conditions at the fruiting stage and thus general intensification and spread of *tirak* were greatly lessened. The internal economy of the plant greatly improved and the plant produced less of sticks and more of fruits. The efficiency of the plant for producing seed cotton rose from a maximum of 20% in the May-sown crop to nearly 50% in the June-sown crop. It produced more seed cotton in proportion to its size. The May-sown crop exhausted itself in producing vegetative growth and reached a state of senescence when bolls began to form. It was, therefore, not able to stand the vagaries of weather which is many a time dry and warm during the fruiting period. The June-sown crop being comparatively young was able to adjust itself to such abnormal fluctuations in its aerial environment.

The only disadvantage that resulted from the June-sowings was a decrease in boll number as the plant scaffolding was lessened, due to a shortened period of vegetative growth but this disadvantage could be adequately offset by thick planting of the crop.

This simple measure of deferring sowings by about three to four weeks, *i.e.* from the first week of May to the last week of May has been found to result in great profits to cotton growers and many of them have already benefited. On some of the farms record yields of seed cotton per acre have been obtained by adopting the sowing time, spacings and seed rates recommended in the two schedules given in Chapter IX.

The cotton crop at the Farm of the British Cotton Growers' Association Khanewal, was frequently subject to intense *tirak* and the yields were generally much below expectation in spite of a high standard of cultivation. The crop was found by the author to suffer severely from *tirak* in 1937, 1938 and especially in 1939 when the crop had completely failed. The cotton sowings on this farm used to start from the 1st of May and to complete by the beginning of June. Thus 90% of the total acreage under cotton was planted in the month of May. The annual acreage under the crop was about 1600 acres. In 1940 on the advice of the writer, the cotton sowings were shifted to the month of June and the crop was planted closer and closer with each advancing week in June. This practice has since been continued. During the last three years the cotton sowings were completed within the first three weeks of June to avoid damage caused by Jassids in a Jassid year like 1944 which proved to be the worst Jassid year in the history of the American cottons in the Punjab.

During these seven years of the adoption of this improved practice of cotton sowings the crop had not suffered to any appreciable extent from this 'disease' even though 1941 and 1946 were partial *tirak* years on account of unusually hot and dry weather during the fruiting period. The cotton yields of the Farm even in these two years were normal.

In order to get an approximate idea of the benefit derived by the British Cotton growers' Association Farm during these seven years on account of late sowings, the average yields per acre for the last seven years 1940 to 1946 were compared with the average yields per acre for the previous seven years 1933 to 1939 when the cotton sowings were done in the month of May at 3 feet distance. The period of seven years was regarded sufficiently long for such an estimate of benefit as the seasonal effects on yield may be expected to average out during this period.

TABLE LXXXIV

Year	*May sown crop.*							
	1933	1934	1935	1936	1937	1938	1939	Mean
Yield of seed cotton in maunds per acre ..	12.40	10.56	8.06	12.76	7.77	7.42	3.65	8.95
						1 maund	= 82.2	lbs.
			June-sown crop.					
Year	1940	1941	1942	1943	1944	1945	1946	Mean.
Yield of seed cotton in maunds per acre	14.56	9.75	16.50	9.05	5.30	11.5	13.0	11.38

It was clear that the average yield of seed cotton per acre had increased by about two and a half maunds (200 lbs.) during the last seven years of late sowings with closer spacings. Taking the average price for seed cotton during these years at Rs. 15 per maund, this Farm derived annually an extra benefit of Rs. 60,000 from their 1600 acres under cotton for the last seven years. Thus the total benefit derived by this one Farm alone amounted to a sum larger than that expended by the Indian Central Cotton Committee on this investigation in the Punjab. The reader can very well gauge the benefit that would be dreived when this remedy of comparatively late sowings with close spacings would be practised over two and a half million acres of cotton in the Punjab and Sind and the changes it would bring about in the economy of these provinces has been left to the reader to calculate.

The same measure of deferring sowings by two to three weeks in different parts of Sind proved successful in ameliorating the 'bad opening' of bolls in Sind-American cottons, as the same two soil types that were found in the Punjab were again found to be associated with the 'bad opening' of bolls in Sind-American cottons.

As a shift in the sowing period of cottons in Sind was found necessary to minimise the damage caused by the 'bad opening' of bolls, the optimum sowing periods for cottons in combination with close spacing for different varieties and for different parts of Sind were determined by laying out factorial experiments. In all 38 sowing date experiments were conducted and the sowing period for cotton in each part of Sind was fixed.

Numerous attempts have been made in the past to correlate weather conditions with crop production and cotton yields have not been omitted from such studies. The difficulties involved in such studies have also been realised. In the case of cotton, the yields would depend on the number of bolls produced per plant, which in turn would depend on the vegetative structure, *i.e.*, growth. Growth is the final

product of the metabolic machinery which is made up of numberous interlinked and interdependent physiological processes. These processes are greatly affected by fluctuations in weather factors. Each one is accelerated or decelerated to a different degree by any change in a weather factor. Thus day-to-day variations in weather conditions and the variations in their duration will bring about changes in all the functional activities of the plant. The interrelations between the two are so complex that it would be difficult to attribute to a particular weather factor any increase or decrease in the growth rate of the plant. To this must be added the capacity of the plant for adjustment and rapid recovery. It is, therefore, not surprising to find that the attempts made to correlate weather factors with yields have proved unsuccessful.

The correlation studies between temperature and yields of cotton in the Punjab have produced some definite results on account of certain advantages. *Tirak* 'disease' was known to depress the yields. The causes of *tirak*, the stage at which the symptoms developed and the interaction of soil salinity with temperature on development of *tirak* also became known. So only the weather factors at the fruiting stage which aggravated the condition of physiological drought had to be studied. The maximum temperature was found to be the important factor. Even then, the standard methods of determining the correlations between yields and temperature did not work and recourse had to be taken to an arbitrary method of selecting such spells of hot weather in the two fruiting months when the temperature rose above the normal monthly mean of maximum temperature. A definite negative correlation between the degrees above the normal monthly mean of maximum temperature in a spell of eight days or more and yields became evident even though in some cases the value of correlation coefficient did not reach the level of significance. Though this method of taking the temperatures of the spells may be considered arbitrary it is quite sound from a physiological point of view as the greatest disturbance in the metabolic activities of the plant would be caused during the hot spells irrespective of the fortnightly or the monthly means.

The frequent and widespread occurrence of the yellow-red leaf disease in Sind-American cottons was another instance where the interaction between a soil factor and a climatic factor produced the spread of a physiological 'disease.' Though the yellow-red leaf was associated with light sandy lands both in Sind and the Punjab, its frequent and widespread occurrence in South and East Sind was caused by the prevailing high night temperatures during the fruiting stage which hastened the maturation of the crop. It was found that the bolls in this tract opened in 32 to 40 days after setting as compared with 45 to 70 days in the middle Sind and the Punjab. The whole crop in South and East Sind matured within two months; September-October, *i.e.*, much before the night temperatures dropped to 65° F. The rapid maturation of the crop rapidly depleted the leaves of their nitrogen which turned yellow and subsequently red. The disease thus not only appeared on very light sandy lands but it also developed on light sandy loams where it did not appear normally in the Middle Sind or the Punjab where the crop matured slowly on account of the falling night temperatures from the month of October to January.

The remedial measure to lessen the spread of the disease on light sandy lands containing more than 60% of sand has been recommended and a rapid method of locating such fields has been worked out.

The above conclusions applied to the yellow-red leaf disease in Sind-American cotton in Sind. There was, however, another type of leaf-reddening which was not

preceded by the yellowing of leaves. The change in colour in this case occurred from green to red without the intervening stage of yellowing. Such reddening of leaf occurred on heavier types of land containing more of clay and less of sand. The green-red type was quite distinguishable from the yellow-red type on soils containing less than 45% of sand. Manuring with sulphate of ammonia did not increase the yield on these heavier types of soils in Sind indicating that the green-red type was not associated with a nitrogen deficiency. More work was, however, needed to determine the causes of this type of leaf reddening in Sind.

The discovery of "tannin" accumulations in the leaves of cotton may pave the way to the solution of many other cotton problems. So far, its association with a low level of nitrogen and low bearing had been pointed out. It was definite that the accumulation of this substance retarded the normal functional activities of the leaves. The physiological role played by this substance and the causes which lead to its accumulation were not at present understood. The presence of this substance in the leaves of upland cottons suffering from the "red leaf" disease was of great significance. The method of detecting the presence of this substance was easy and should prove a very handy tool for the cotton workers in their investigations.

It was clear from the results obtained in these investigations that nitrogen applications increased the meristematic activity of the cotton plant. The boll production was increased on account of an increase in the bearing points. It had also been found that a low potassium content in the bolls was associated with the immaturity of cotton seeds on both soil types. The potash deficiency was found to cause a disturbance in the synthesis of proteins and fats. Some of the seeds in the boll were, therefore, not able to mature fully. Many other instances of crop plants were already known where a potash deficiency was associated with an inhibition of the protein synthesis and the immaturity of seeds. Deficiency of potash in *tirak*-affected plants on the two soil types appeared to arise in different ways. On light sandy soil the uptake of potash was lessened on account of a deficiency of nitrates in that soil. Potash deficiency in *tirak*-affected plants on soils with saline subsoils developed on account of the physiological drought that interfered with the absorption of nutrients, of which potash was one. The common symptom of immaturity of seeds, therefore, appeared on both soils but the symptoms exhibited by the leaves of *tirak*-affected plants on the two soils were found to differ.

This investigation has also shown that the problem of manuring of American cottons in the Punjab was beset with difficulties. The manuring of American cotton in the Punjab with sulphate of ammonia cannot be recommended as a general measure, as it has been found ineffective in increasing the yields on soils which are saline. As non-saline and saline lands are intermingled, the manuring becomes unprofitable as the gain in yields obtained on non-saline areas would be neutralized by the absence of any increase in yield on the saline areas.

Though a general recommendation on the manuring of American cottons in the Punjab cannot be made, a simple method of testing the leaves for the "*tannin*" reaction has been discovered for spotting cotton fields in the month of August where manuring of cotton with sulphate of ammonia would give profitable returns. The application of this method for three successive seasons in *zamindars'* fields has proved very successful. This method can be adopted by intelligent *zamindars* on their cotton fields and great benefit would be derived by the use of sulphate of ammonia on such fields where the leaves of American cottons give the "tannin" reaction.

It was observed and subsequently demonstrated by properly replicated experiments conducted for four years that while the June-sown 4F crop spaced widely (2 ft. x 2 ft. and 2½ ft. x 2½ ft.) was heavily infested by Jassids in a Jassid year, the same crop sown near by on the same date but spaced closely (1 ft. x 1 ft. and 1½ ft. x 1½ ft.) was less infested by this insect pest. This finding is of great scientific as well as of practical importance, as it is the most effective way of controlling the pest and reducing the damage to the June-sown crop. The causes that operate in preventing the insect from damging a closely spaced crop remained to be determined. It appears both the biochemical and ecological factors are involved and investigations on these lines may prove of value.

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